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Final Report
Conceptual Model of Ozone Formation in the Killeen-Temple-Fort Hood Area

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LIST OF ACRONYMS AND ABBREVIATIONS

AACOG	Alamo Area Council of Governments
APCA	CAMx Anthropogenic Precursor Culpability Assessment
ARPDB	Acid Rain Program Database
ATV	All-terrain vehicle
BACT	Best available control technology
BCs	Boundary Conditions
BPA	Beaumont-Port Arthur Area
BSASI	Barnett Shale Area Special Inventory
CAMD	Clean Air Markets Division
CAMS	Continuous Air Monitoring Station
CAMx	Comprehensive Air Quality Model with Extensions
CAPCOG	Capital Area Council of Governments
CEM	Continuous emissions monitor
CO	Carbon monoxide
CTCOG	Central Texas Council of Governments
CTG	Combustion turbine generation
DFW	Dallas-Fort Worth
ECS	Equipment Concentration Site
EGU	Electric Generating Unit
EPA	Environmental Protection Agency
DV	Design value
DVs	Design values
EDAS	Eta Data Assimilation System
EGU	Electric generating unit
EIA	Energy Information Administration
EPA	Environmental Protection Agency
FSA	Farm Services Agency
HAP	Hazardous air pollutant
HGB	Houston-Galveston-Brazoria Area
HOTCOG	Heart of Texas Council of Governments
Hr	Hour
HYSPLIT	Hybrid Single Particle Lagrangian Integrated Trajectory Model
H4MDA8	Annual 4th highest daily maximum 8-hour average ozone
ICs	Initial Conditions
KTF	Killeen-Temple-Fort Hood
kW	Kilowatt
LCC	Lambert Conic Conformal
M	Thousand
MATES	Military Equipment and Training Site
MEGAN	Model of Emissions of Gases and Aerosols from Nature
MDA1	Daily maximum 1-hour average
MDA8	Daily maximum 8-hour average

MOBILE6.2	Mobile source emissions model (predecessor to MOVES)
MOVES	Motor Vehicle Emissions Simulator
Mph	Miles per hour
NAA	Non-Attainment Area (for the ozone NAAQS)
NAAQS	National Ambient Air Quality Standard
NEI	National Emission Inventory
NMB	Normalized Mean Bias
NME	Normalized Mean Error
NNA	Near non-attainment area
NO	Nitric oxide
NO_2	Nitrogen dioxide
NOx	Oxides of nitrogen
O_3	Ozone
OSAT	CAMx Ozone Source Apportionment Tool
OSD	Ozone season day
ppb	Parts per billion
PX	Pleim-Xiu land surface model
RPO	Regional Planning Organization
SCC	Source classification code
Scf	Standard cubic feet
SIC	Standard industrial classification
SIP	State Implementation Plan (for the ozone NAAQS)
SO_2	Sulfur dioxide
STARS	State of Texas Air Reporting System
TAC	Texas Administrative Code
TCEQ	Texas Commission on Environmental Quality
Ton	English short ton (2000 pounds)
tpd	Tons per day
TRC	Texas Railroad Commission
TXDOT	Texas Department of Transportation
USDA	United States Department of Agriculture
VMT	Vehicle miles travelled
VOC	Volatile organic compound
WRF	Weather Research and Forecast model
YSU	Yonsei University WRF planetary boundary layer parameterization
yr	Year

1.0 EXECUTIVE SUMMARY

The purpose of a conceptual model for ozone is to assemble in one place relevant information about factors that contribute to high ozone in an area. Ground level ozone is not emitted directly but is formed in the atmosphere from chemical precursor species in the presence of sunlight. High ozone results from a combination of factors. Light winds can allow ozone and precursors to accumulate over an area and are often associated with high ozone. Strong sunlight and high temperatures are also typically associated with high ozone in urban areas. There are natural sources of ozone and precursors, so that there is an ozone background which has a variable contribution that depends on location and weather conditions. Ozone can persist in the atmosphere on time scales of days to weeks and this allows transport between cities, states, and even continents. This means there is often a transported ozone background from human activities as well as natural sources. While ozone problems can be due to transport alone, this is relatively rare. In most areas, the ozone problem is due to both local precursor emissions sources and ozone transport.

The extent to which actions by a local area can reduce ozone depends upon the magnitude of the contribution of local precursor emissions to ozone. Jurisdiction over emission sources rests primarily with the Federal and State governments. Local areas can influence emissions of ozone precursors through local ordinances, voluntary actions that provide reductions beyond or sooner than Federal and State requirements, and by active participation in air quality planning processes to bring relevant information into policy decisions.

This report presents a conceptual model of ozone for the Killeen-Temple-Fort Hood (KTF) Area of Texas. The KTF Area consists of San Saba, Mills, Lampasas, Coryell, Hamilton, Bell, and Milam Counties. This conceptual model incorporates the results of a review and analysis of air quality, emissions and meteorological data as well as the results of photochemical modeling. A summary of the conceptual model, which is based on data through the end of the 2014 ozone season, is given below.

1.1 Meteorology

The KTF Area is located on the eastern edge of the Edwards Plateau in Central Texas, where the lack of major topographical features means that wind patterns are driven primarily by synoptic-scale meteorological influences. Episodes of high ground level ozone (> 75 ppb) in the KTF Area occur most often between June and September when the area is under the influence of a semi-permanent subtropical high-pressure system, vertical mixing of pollutants in the atmosphere is restricted, skies are clear to partly cloudy, temperatures are high, and winds are light. These conditions which are conducive to ozone formation can also be produced by passage of a cold front or the presence of a stationary front. Most ozone episodes are associated with light near-surface winds from the north/east/south/southwest, with southerly directions appearing less frequently on days with highest ozone. Days during the ozone season with low ozone (< 60 ppb) in the KTF Area occur during periods of strong southerly winds that bring comparatively less polluted maritime air from the Gulf of Mexico northward into Central Texas.

1.2 Emissions

The most recent available inventory of anthropogenic and biogenic ozone precursor emissions for the KTF Area is the Texas Commission on Environmental Quality's (TCEQ) 2012 emission inventory. KTF Area-wide ozone season day emission estimates are 62 tons per day (tpd) of nitrogen oxides (NOx) and 1,026 tpd of volatile organic compounds (VOC). Biogenic emissions are by far the largest VOC category comprising 978 tpd of KTF Area VOC emissions. The presence of abundant biogenic VOC emissions ensures that there are typically sufficient VOC to allow ozone formation and, consequently, that the potential ozone impact of KTF Area emissions is determined by NOx emissions. Photochemical modeling of a June 2012 ozone episode using the Comprehensive Air Quality Model with Extensions (CAMx; Ramboll Environ, 2015) ozone source apportionment capability supports the emissions inventory determination that ozone formation in the KTF Area is limited by the amount of available NOx. This indicates that local emissions control strategies aimed at reducing local contributions to KTF Area ozone should focus on reducing NOx emissions.

The KTF Area has large population centers to its north, southeast and south. The KTF Area is located approximately 60 miles north of Austin, 150 miles northwest of Houston, 45 miles southwest of Waco and 130 miles south of the DFW area. The KTF Area's 2012 NOx emissions were far smaller than NOx emissions from the Austin, Houston, Waco and DFW areas.

We used the CAMx ozone model to quantify the contribution of KTF Area emissions to ozone at the TCEQ Continuous Air Monitoring Station (CAMS 1047) in Killeen. We separated the ozone contribution from KTF emissions at the monitor into contributions from different emissions source categories. The episode average contribution from all KTF Area emissions to the daily maximum 8-hour average (MDA8) at the Killeen monitor was 3.2 ppb. Of all KTF Area emissions source categories, emissions from on-road mobile sources (cars, trucks, etc.) made the largest contribution to ozone at the Killeen monitor (episode average of 1.8 ppb; 56% of KTF Area contribution). The Killeen monitor is influenced by emissions from traffic within the Killeen urban area and nearby Fort Hood as well as the Temple urban area. The monitor is located less than a mile north of heavily-trafficked Highway 190, which connects the Killeen-Fort Hood Area with Belton and Temple and Interstate I-35. I-35 is approximately 13 miles west of the Killeen monitor, and is a major highway that has a high volume of automobile and heavy-duty truck traffic.

KTF Area off-road mobile source emissions (locomotives, agricultural, construction and mining equipment) and power plant emissions each contributed a smaller amount of ozone than on-road mobile sources in the June 2012 ozone modeling. The episode average contribution from off-road mobile emissions was 0.9 ppb at the Killeen monitor. The episode average ozone impact from KTF Area power plant emissions was 0.3 ppb, with episode maximum impacts close to 2 ppb at the Killeen monitor. Power plant emissions in the KTF Area consist entirely of emissions from the coal-fired Sandow Power Plant in Milam County. Ozone impacts of Sandow emissions were higher (episode maximum of 12 ppb) away from the Killeen monitor. The location of the Sandow plume varied from day to day based on the wind direction and the highest Sandow ozone impacts occurred to the south and east of the plant during the June

2012 episode. The modeling results indicate that during different wind conditions than occurred during the June 2012 episode, it would be possible for the Sandow plume to influence the Killeen and Temple Georgia monitor MDA8 values at a higher level (up to 4 ppb). We therefore recommend that SO_2 monitoring be performed at Killeen and Temple Georgia. Coal-fired power plant plumes are characterized by the presence of SO_2, which is released into the air during combustion of coal. The presence or absence of SO_2 along with ozone in a plume can help identify emissions source(s) influencing a monitor on a high ozone day. Emissions from KTF area sources, oil and gas sources and non-power plant point sources made relatively small contributions (0.1 ppb or less on average) to the MDA8 ozone at the Killeen monitor.

In 2012, the Killeen monitor was the only CAMS ozone monitor operating in the KTF Area. The Temple Georgia monitor (CAMS 1045) began operation in 2014. The ozone model's source apportionment capability allows us to examine ozone contributions for locations that do not have monitoring sites active during the modeled episode, so we reviewed the source apportionment for the location of the Temple Georgia monitor as well as for population centers in each of the KTF Area counties. Results for each of these virtual monitor locations were qualitatively similar to those of the Killeen monitor.

1.3 Ozone Transport

Ozone source apportionment modeling for the June 2012 episode was used to estimate transported contributions to ozone at the Killeen monitor and the location of the Temple Georgia and other virtual monitors from emissions source regions outside the KTF Area; this included emissions source regions within and outside of Texas. Results for the virtual monitors in all KTF Area counties were similar to those shown below for Killeen and Temple Georgia.

On average, ozone transported into the KTF Area contributed far more (49-51 ppb) than local KTF Area emissions (3.2 ppb for both monitors) to the daily maximum 8-hour average (MDA8) ozone at the Killeen and Temple Georgia monitors (Figure 1-1). However, the KTF Area contribution to MDA8 ozone at Killeen and Temple Georgia monitors varied from day to day in the range 0.1 to 13 ppb and 0.1 to 12 ppb, respectively, during the June 2012 ozone modeling episode.

The photochemical modeling results indicate that, while ozone at the locations of the Killeen and Temple Georgia monitors is largely due to transport, local emissions controls may have some potential benefit in reducing MDA8 ozone at the two monitors. The fact that the local KTF Area contribution to ozone reached 12-13 ppb at Killeen and Temple Georgia monitors means that local sources can produce intermittent large impacts that are of particular concern because they have the potential to drive up the ozone design value by affecting the monitor on dates that enter into the design value calculation.

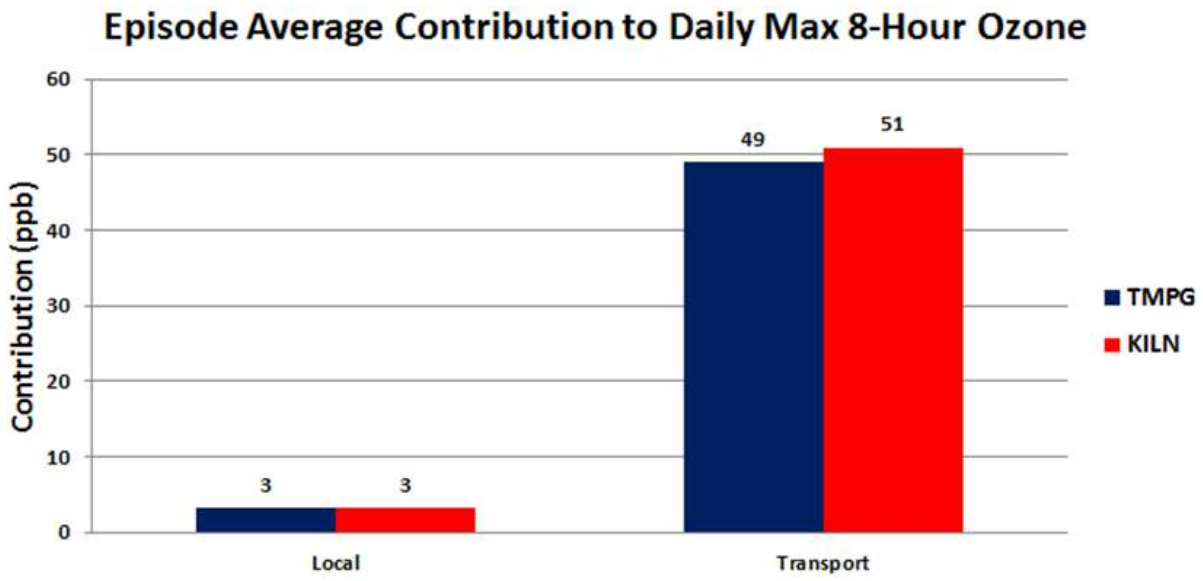

Figure 1-1. Episode average contribution to daily maximum 8-hour ozone for the location of the Temple Georgia (TMPG; CAMS 1045) monitor and the Killeen (KILN; CAMS 1047) monitor from KTF Area emissions sources ("local") and all emissions sources outside of the KTF Area ("transport").

The ozone modeling results showed that, on average, transport contributes far more to KTF ozone than emissions from local KTF Area sources. The contribution of KTF Area emissions accounted for 3.2 ppb of the episode average 8-hour ozone at the Killeen monitor while the Austin area contributed 6.1 ppb. On a day-to-day basis, the local ozone contribution to MDA8 ozone from KTF Area emissions reached a maximum value of 12.5 ppb at the Killeen monitor, while three Texas regions (Houston, Austin and Waco) each contributed larger maximum amounts (up to 19 ppb, 16 ppb and 13 ppb, respectively).

Our evaluation of ozone model performance in simulating observed ground level ozone in June 2012 showed that the model has a general tendency to overestimate ozone at monitors across East Texas. At the Killeen monitor, the model captures much of the observed ozone variability and has an overall high bias, but underestimates peak ozone by as much as 16 ppb on days when observed ozone exceeds 70 ppb. The cause of this low bias on all five days with ozone > 70 ppb at Killeen is not known, but should be investigated. Potential causes include uncertainty in the local KTF emissions inventory and error in modeled winds. While these biases can affect the details of the model results, they should not significantly affect the nature of the ozone source apportionment analysis presented in this report.

1.4 Summary of Findings

- Biogenic emissions are the largest KTF Area VOC emissions category
- Local emissions control strategies aimed at reducing local contributions to KTF Area ozone should focus on reducing NOx emissions

- The KTF Area's 2012 NOx emissions were far smaller than NOx emissions from the Austin, Houston, Waco and DFW areas
- The episode average contribution from all KTF Area emissions to the daily maximum 8-hour average at both the Killeen monitor and the Temple Georgia monitor was 3.2 ppb
- Of all KTF Area emissions source categories, emissions from on-road mobile sources (cars, trucks, etc.) made the largest contribution to ozone at the Killeen monitor followed by off-road sources (locomotives, construction, agricultural and mining equipment) and the Sandow Power Plant
- On average, transport contributed far more to ozone at KTF Area monitor locations (49-51 ppb) than emissions from local KTF Area sources (3.2 ppb) during the June 2012 episode
- Areas of Texas contributing the most to KTF Area ozone were Austin, Houston, and Waco
- While ozone at the locations of the Killeen and Temple Georgia monitors is largely due to transport, local emissions controls may have some potential benefit in reducing MDA8 ozone at the two monitors
- The fact that the local KTF Area contribution to ozone reached 12-13 ppb at Killeen and Temple Georgia monitors means that local sources can produce intermittent large impacts that are of particular concern because they have the potential to drive up the DV by affecting the monitor on dates that enter into the DV calculation

1.5 Recommendations for Future Work

Based on the analyses developed to support Conceptual Model development, we recommend the following as high priority areas for future work:

- Emissions from Fort Hood military post off-road equipment, area sources, on-road vehicles, and point sources are highly uncertain and may be underestimated in the TCEQ 2012 emission inventory. Specific sources of uncertainty that should be addressed are off-road emissions from sources such as military vehicles and aircraft; industrial area sources (e.g. solvent usage, degreasing); on-base civilian vehicle emissions; and criteria that were used to determine which emission sources were reported in the Fort Hood point source emission inventory.
- Review ozone precursor emissions and estimate ozone impacts from the new Panda Temple Power Generating Station, which is located in Bell County approximately 8 miles southeast of the Temple Georgia ozone monitor. Because the Panda Temple Station was not yet operating in 2012, its impacts on KTF Area ozone were not evaluated in this study. The potential ozone impacts of this facility should be modeled in order to understand its influence on ozone at the Temple Georgia and Killeen ozone monitors.
- Diagnose cause(s) of the June 2012 ozone model's low bias on high ozone days at Killeen and improve model performance on these days

- Perform an evaluation of Weather Research and Forecast (WRF) meteorological model performance at the Killeen monitor and other airport weather monitoring stations within the 7-county area. The WRF model was used to supply weather data to the CAMx ozone model in the June 2012 modeling. The KTF Area is greatly influenced by transported ozone, and wind speed and wind direction errors can contribute to ozone biases at the Killeen monitor.
- Perform a more complete ozone model performance evaluation that examines representative monitors in Texas regions that significantly contribute to ozone in the KTF region. Since the KTF region is strongly influenced by transported ozone, it is important to accurately predict ozone formed outside of the KTF region.

2.0 INTRODUCTION

Ozone is the main ingredient in photochemical smog. Ozone affects human lung function, increasing the prevalence and severity of asthma and bronchitis, and damages vegetation. Ozone is not emitted directly into the atmosphere, but forms from nitrogen oxides (NOx) and volatile organic compounds (VOCs) in the presence of sunlight. NOx and VOCs are emitted by both natural processes and human activities. Conditions that favor the formation of ground-level ozone are strong sunlight, high temperatures, and high precursor (NOx and VOC) concentrations. High precursor concentrations in the atmosphere occur when emissions are large and/or weather conditions allow precursors to accumulate. When winds are calm and the atmosphere is stable, emitted precursors do not disperse and are available for ozone formation. On the other hand, if the atmosphere is unstable, ozone and precursors can be transported aloft away from the ground, and if winds are brisk, emitted pollutants are transported away from the area so that ozone does not build up.

Ozone is removed from the atmosphere by chemical reactions, photolysis (destruction by sunlight), deposition onto surfaces and uptake by plants. Ozone has a lifetime of several days to weeks at ground level; this lifetime is long enough to allow ozone to be transported thousands of miles. At any given location, therefore, measured ozone is partly due to a contribution from local emissions and partly due to transported ozone, which is often referred to as background ozone. High background ozone exacerbates local ozone problems, but is not a necessary condition for an area to have high ozone. Ozone problems solely from transport can occur, but are rare.

In order to reduce ozone in a given area, the ozone problem must be studied to determine the relative importance of local emissions and transported ozone. Photochemical modeling is used to assess the magnitude of the local and transported contributions. Regional and national emissions control measures such as the Federal vehicle emissions standards aim to reduce the contribution from transported ozone. If local ozone precursor emissions are shown to contribute to ozone levels, then local emissions control measures can be developed.

The U.S. EPA sets a National Ambient Air Quality Standard (NAAQS) for ozone in order to protect public health and the environment. The NAAQS is based on health impacts for sensitive groups and there are economic penalties for areas that fail to attain it. The NAAQS is violated at an ozone monitor if the annual fourth highest daily maximum 8-hour average concentration (MDA8) averaged over three consecutive years exceeds a threshold value, which is set at 75 parts per billion (ppb). A single year of data is not considered sufficient to demonstrate attainment. Consequently, this statistic is referred to as the annual 8-hour design value (DV).The eight-hour ozone NAAQS is currently set at 75 parts per billion (ppb).

The TCEQ operates two Continuous Air Monitoring Station (CAMS) ozone monitors in the KTF Area that determine whether the Area is in compliance with the NAAQS: the Killeen Skylark monitor (CAMS 1047) and the Temple Georgia monitor (CAMS 1045), both located in Bell County. The Killeen monitor began operating on June 11, 2009, and the Temple Georgia monitor has been operational since October 4, 2013. In 2011, all counties in the KTF Area were

designated by the EPA as being in attainment of the ozone NAAQS based on the 2008-2010 readings from the Killeen Skylark monitor. At the end of the 2014 ozone season, the Killeen Skylark monitor had a design value of 72 ppb; this design value is in compliance with the 2008 ozone NAAQS of 75 ppb. The Temple Georgia monitor does not yet have the required three years of data to form a design value.

Under the Clean Air Act, the EPA is required to review the NAAQS periodically. On November 26, 2014, the EPA announced their intention to lower the eight-hour ozone NAAQS to a value in the 65-70 ppb range and to finalize the NAAQS by October, 2015 (EPA, 2014a). Designations of attainment status are anticipated by October, 2017 and will likely be based on monitored ozone levels in 2014, 2015 and 2016. Depending on where the NAAQS is set, one or both of the KTF Area monitors could be out of compliance. Because failure to comply with the NAAQS carries adverse public health impacts and significant economic penalties, ozone air quality planning is important for the KTF Area.

One of the first activities to be completed in the development of an ozone State Implementation Plan is the formulation of a "conceptual model" of ozone for the area. This provides a qualitative understanding of the general nature of the ozone situation in a region, including a discussion of regional ozone transport, and formation of ozone from local precursor emissions. EPA guidance (EPA, 2007; 2014b) specifies that the key components of the conceptual model are analyses of air quality, meteorological and emissions data. Through these analyses, relationships between weather conditions and high ozone events may be established, important emissions sources and trends may be identified, and periods of high ozone suitable for modeling may be selected. Ozone modeling may be used to shed light on the causes of high ozone events as well as the likely effectiveness of proposed emission control strategies. As the KTF Area prepares for possible participation in SIP development, it is appropriate to develop a conceptual model of ozone for the Area.

The objective of this study was to develop a conceptual model of ozone formation in the KTF Area using ambient data from 2009 through the end of the 2014 ozone season, emission inventory data from 2006 and 2012 and photochemical modeling of a June 2012 high ozone episode. We identified necessary and sufficient conditions for high and/or exceeding ozone measurements at the Killeen and Temple ozone monitors. Exceeding ozone measurements are currently 8-hour average values higher than the NAAQS of 75 ppb, but we also analyzed lower thresholds in light of the potential for a new, more stringent NAAQS. The conceptual model includes the following analyses:

- Analysis of trends in the annual frequency of high ozone days and trends in the severity of high ozone at Killeen, Temple and surrounding monitors
- Evaluation of wind speeds and directions on high ozone days to determine the local wind conditions and directions most frequently associated with high ozone
- Analysis of weather conditions frequently associated with high ozone days in the KTF Area

- Development of back-trajectories to determine source regions most and least likely to transport precursor emissions and ozone into the KTF Area
- Analysis of weekday/weekend variations in monitored ozone to evaluate the potential effectiveness of reduced levels of on-road mobile source emissions or other day-specific source categories within the Area
- Review of the TCEQ's KTF Area ozone precursor emission inventories for 2006 and 2012 including a summary of the emission inventory by emissions source category and evaluation of overall VOC/NOx ratio.
- Analysis of photochemical grid model source apportionment results, including an assessment of the relative importance of local versus distant emissions sources on ozone levels in the KTF Area and a determination of whether ozone formation in the KTF Area is NOx- and/or VOC-limited.
- Review of additional relevant questions listed in Section 11.1.1 of EPA's ozone modeling guidance document, Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, PM2.5, and Regional Haze. (EPA, 2007; 2014b).

In Section 3 of this report, we review trends in ozone in the KTF Area and the surrounding region. In Section 4, we present an analysis of the TCEQ's 2012 emission inventory of ozone precursors for the KTF Area and examine trends in anthropogenic emissions between 2006 and 2012. Section 5 contains an ambient data analysis that includes an investigation of the possible relationships between weather conditions and high ozone, and identifies meteorological phenomena associated with high ozone. In addition, analyses linking specific wind directions and long-range atmospheric transport patterns to high ozone are presented. Photochemical modeling of a June 2012 high ozone episode and ozone source apportionment results are described in Section 6. Finally, conclusions and recommendations are presented in Section 7. An overview of the KTF Conceptual Model is provided in the Executive Summary.

3.0 OZONE TREND ANALYSIS

3.1 Regional Setting and Monitor Location

Figure 3-1 shows the seven KTF counties and the surrounding region. Urban areas are shaded according to population estimates for the year 2010. Major roadways such as Interstate I-35 are shown in blue and highways are shown in light brown. The locations of KTF Area ozone monitors are also presented in Figure 3-1.

The KTF Area is located generally north of Austin and south to southwest of the Dallas-Fort Worth-Arlington (DFW) Metropolitan Statistical Area. Killeen is approximately 60 miles north of Austin, 45 miles southwest of Waco and 130 miles south of the DFW area. Austin had an estimated 2010 population of 810,759[1] and the DFW area had an estimated 2010 population of 6,371,773[2] and was the fourth largest metropolitan area in the U.S.[3]. Ozone precursor emissions, such as NOx or VOCs, from both Austin and the DFW area have been shown to influence ozone concentrations at the Killeen-Skylark monitor within the KTF Area (Parker et al., 2013). In addition, ozone precursor emissions from other less populous urban areas that are located closer to the Bell County monitors can also influence ozone in the KTF Area. In particular, Killeen, Waco and Temple were estimated by the 2010 Census to have populations of 127,911[4], 124,810[5], and 66,312[6], respectively. Ozone precursor emissions from a variety of different emissions sources (e.g. cars, trucks and industrial facilities) in these urban areas can contribute to ozone concentrations in the KTF Area. Figure 3-1 displays the Interstate highway I-35 intersecting Bell County. I-35 is a major roadway that extends across Texas from Mexico to Oklahoma and passes through Austin and San Antonio as well as Waco and the DFW area. Analysis of the 2006 TCEQ emission inventory for Bell County performed by Parker et al. (2013) suggested that emissions from the heavily-trafficked I-35 highway makes an important contribution to the NOx emission inventory for Bell County.

Three air quality monitors are shown in Figure 3-1. The Killeen-Skylark monitor (CAMS 1047) and Temple Georgia (CAMS 1045) are the only currently active ozone air quality monitors in the KTF Area, and data from these monitors are used to calculate the ozone design values for the KTF Area. The Temple monitor (CAMS 651) operated during 2005-2006 only; however, data from this monitor is useful because it provides information on ozone concentrations in Bell County prior to 2009 when the Killeen monitor became active. Additional information on monitor locations, operators and dates of service is presented in Table 3-1.

[1] http://quickfacts.census.gov/qfd/states/48/4805000.html
[2] http://www.census.gov/population/www/cen2010/cph-t/CPH-T-2.pdf
[3] http://www.census.gov/compendia/statab/2012/tables/12s0020.pdf
[4] http://quickfacts.census.gov/qfd/states/48/4839148.html
[5] http://quickfacts.census.gov/qfd/states/48/4876000.html
[6] http://quickfacts.census.gov/qfd/states/48/4872176.html

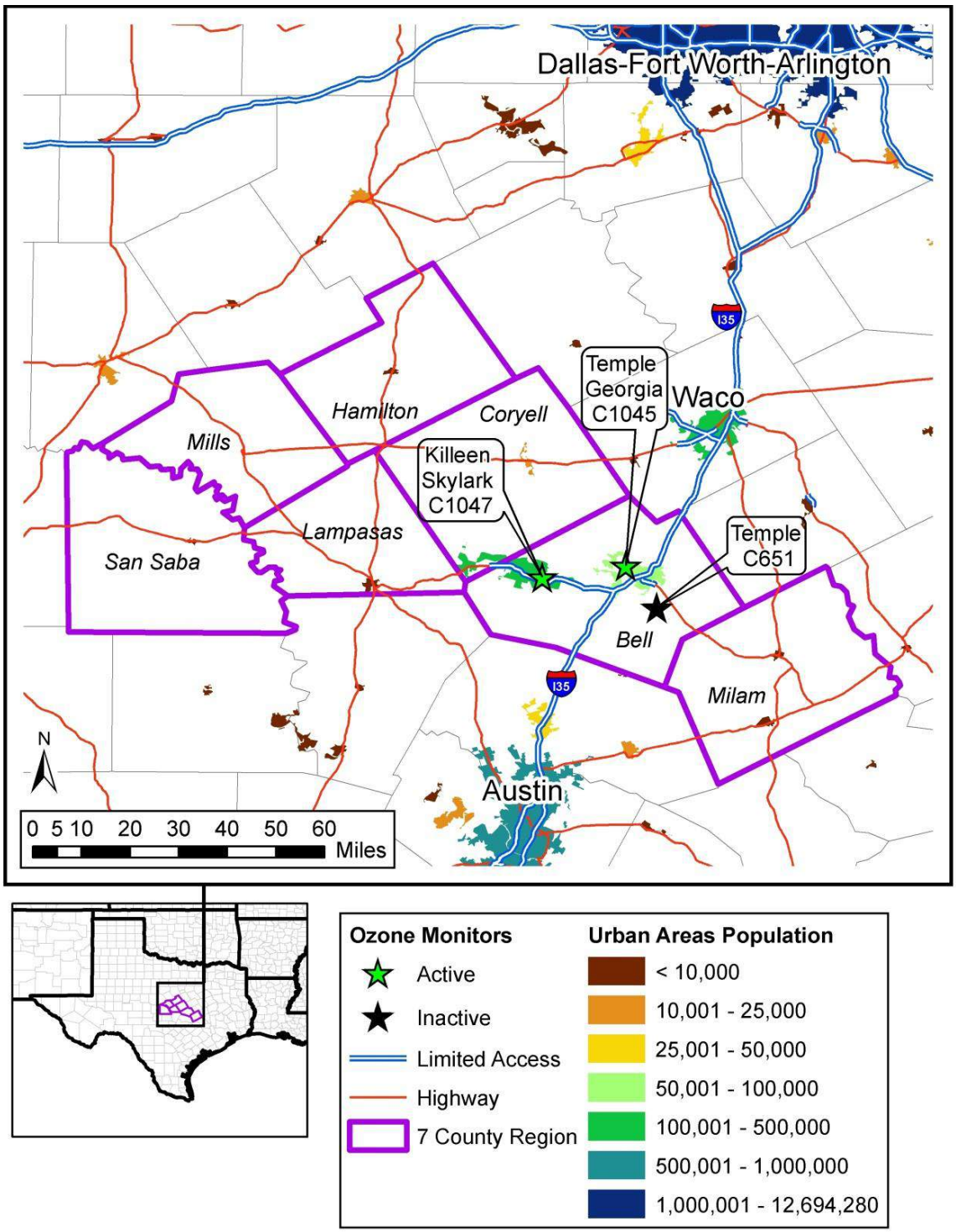

Figure 3-1. The seven county KTF Area, location of CAMS monitors in Bell County, population distributions and major roadways in the surrounding region.

3.2 Ozone Trends in the Killeen-Temple-Fort Hood Area

This section reports on ozone trends based on monitored data from the CAMS monitors in Bell County. Details regarding the monitors are presented in Table 3-1.

Table 3-1. KTF Area ozone monitor information.

	Killeen-Skylark	Temple Georgia	Temple C651
EPA Site Number	480271047	480271045	480270651
CAMS	1047	1045	651
Activation Date	June 11, 2009	October 04, 2013	July 31, 2005
Current Status	Active	Active	Inactive (November 07, 2006)
State	Texas	Texas	Texas
County	Bell	Bell	Bell
City	Killeen	Temple	Temple
Address	1605 Stone Tree Drive	8406 Georgia Avenue	8071 Hwy 95
ZIP	76543	76502	
Latitude	31º 5' 17'' North (31.0880022º)	31º 7' 21'' North (31.1224187º)	30º 59' 51'' North (30.9975000º)
Longitude	-97º 40' 47'' West (-97.6797343º)	-97º 25' 52'' West (-97.4310523º)	-97º 20' 22'' West (-97.3394440º)
Elevation	256.0 m	188.0 m	146.0 m
Owned By	TCEQ	TCEQ	University of Texas at Austin

3.2.1 Annual Ozone Trends at in the KTF Area

The annual 4 highest daily maximum 8-hour average (MDA8) ozone concentrations from the Killeen-Skylark monitor (CAMS 1047) from 2009 to 2014 and Temple Georgia (CAMS 1045) for 2014 are presented in Figure 3-1. Since the Killeen monitor has only 6 years of data and the Temple monitor has only one year of data, it is not possible to assess long term ozone trends at these monitors. At least ten years of data are typically required to assess long term ozone trends due to the important role that meteorology plays in ozone formation. There may be significant year-to-year variability in the number of days per year that are meteorologically conducive to ozone formation. Here, we perform a qualitative review of recent trends in MDA8 at the Killeen monitors.

Figure 3-2 shows that between 2009 and 2012, the four highest annual MDA8 ozone concentrations (i.e. annual 1st, 2nd, 3rd and 4th highest) at the Killeen-Skylark (CAMS 1047) monitor increased, and 2012 had the largest 1st–4th high annual MDA8 ozone concentrations at Killeen during 2009-2014. In 2012, the highest MDA8 ozone concentration was 87 ppb, and the 2nd, 3rd and 4th highest MDA8 ozone concentrations in 2012 were all 78 ppb. Between 2012 and 2014, the four highest values of MDA8 ozone decreased and the 2014 4th high MDA8 was the lowest since 2009. During 2009-2012, there have been 5 days in total with monitored MDA8

ozone concentrations ≥ 75 ppb at Killeen. These days were analyzed in detail in Parker et al (2013), and were all shown to be days with high background MDA8 ozone that was either region-wide (spanning the Waco, DFW and Austin areas) or present upwind of the KTF Area on that particular day. In addition, Parker et al. (2013) determined that on several of these days, the Killeen monitor was likely influenced by a local source of emissions as well as high levels of regional background ozone. The TCEQ is currently developing an ozone model for the 2012 ozone season; this will allow all of the 1st-4th high ozone days for 2012 shown in Figure 3-1 to be studied using a photochemical grid model. The first and second high MDA8 ozone days for 2012 occurred on August 10 and 11, and the 3rd and 4th high MDA8 days were June 26 and June 27. Ozone source apportionment modeling can provide a determination of the emissions sources and regions affecting Killeen ozone on these days that that influence the trends shown in Figure 3-1. Ozone modeling of June 2012 was performed as part of this study, and in Section 6, we present source apportionment results for June 26 and June 27, 2012.

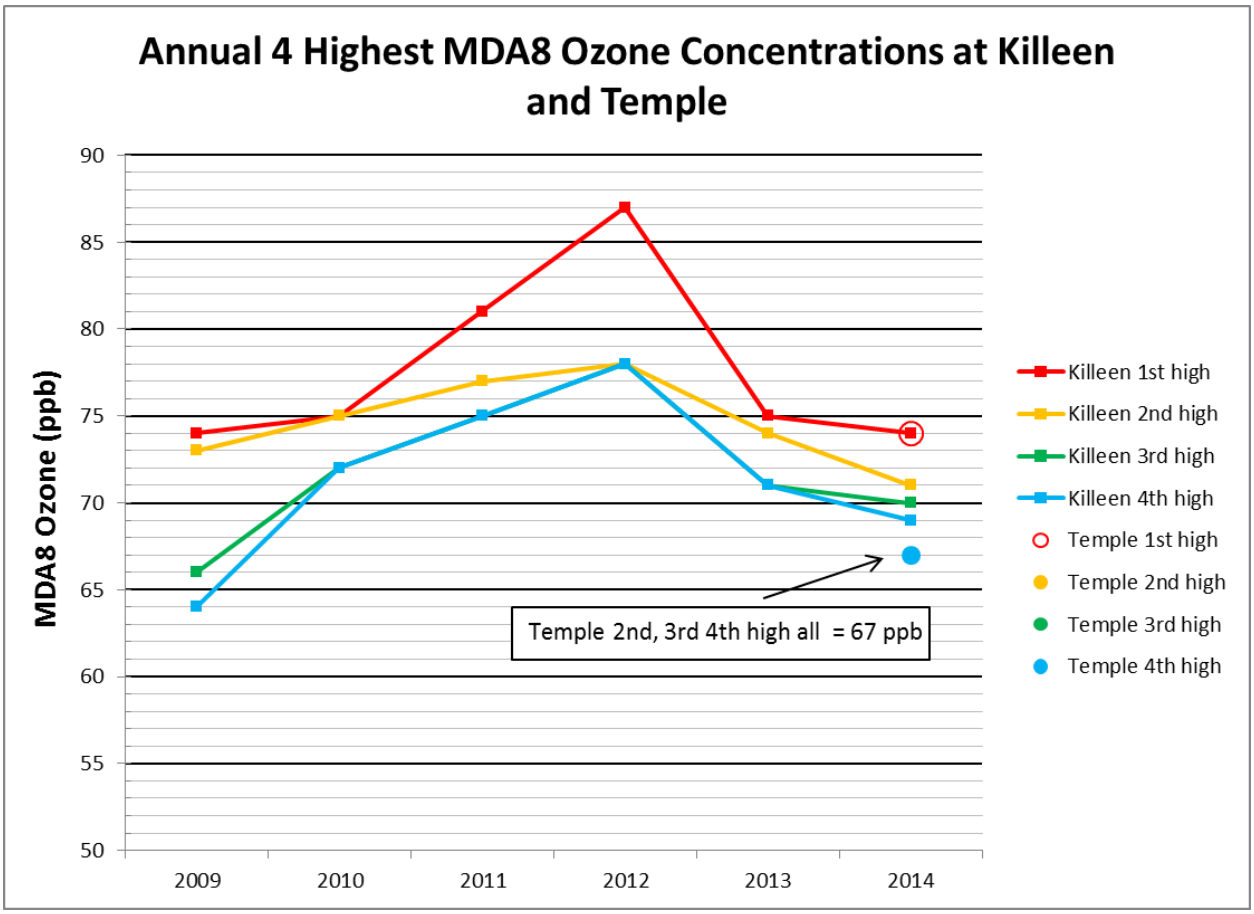

Figure 3-2. 2009–2014 Four Highest Daily Max 8 hour average ozone concentrations at Killeen (CAMS 1047) and 2014 Four Highest MDA8 ozone concentrations at Temple (CAMS 1045).

Figure 3-3 presents the annual 4th highest MDA8 ozone time series shown in Figure 3-2 alongside the corresponding design values (DVs), which are the three-year average of the 4th highest MDA8 ozone values. Figure 3-3 also displays the current NAAQS and proposed NAAQS

range for comparison to the Killeen DVs. The Killeen DV has never exceeded the 2008 NAAQS of 75 ppb, but in 2012, 2013 and 2014, has been higher than the upper bound of the proposed NAAQS range of 65-70 ppb. The Temple Georgia monitor does not yet have a defined DV since 3 years of data are required to form a design value; however, the 4th highest MDA8 is 67 ppb as shown in Figure 3-2. This value is below the 2008 NAAQS but exceeds the lower bound of the proposed NAAQS range of 65-70 ppb.

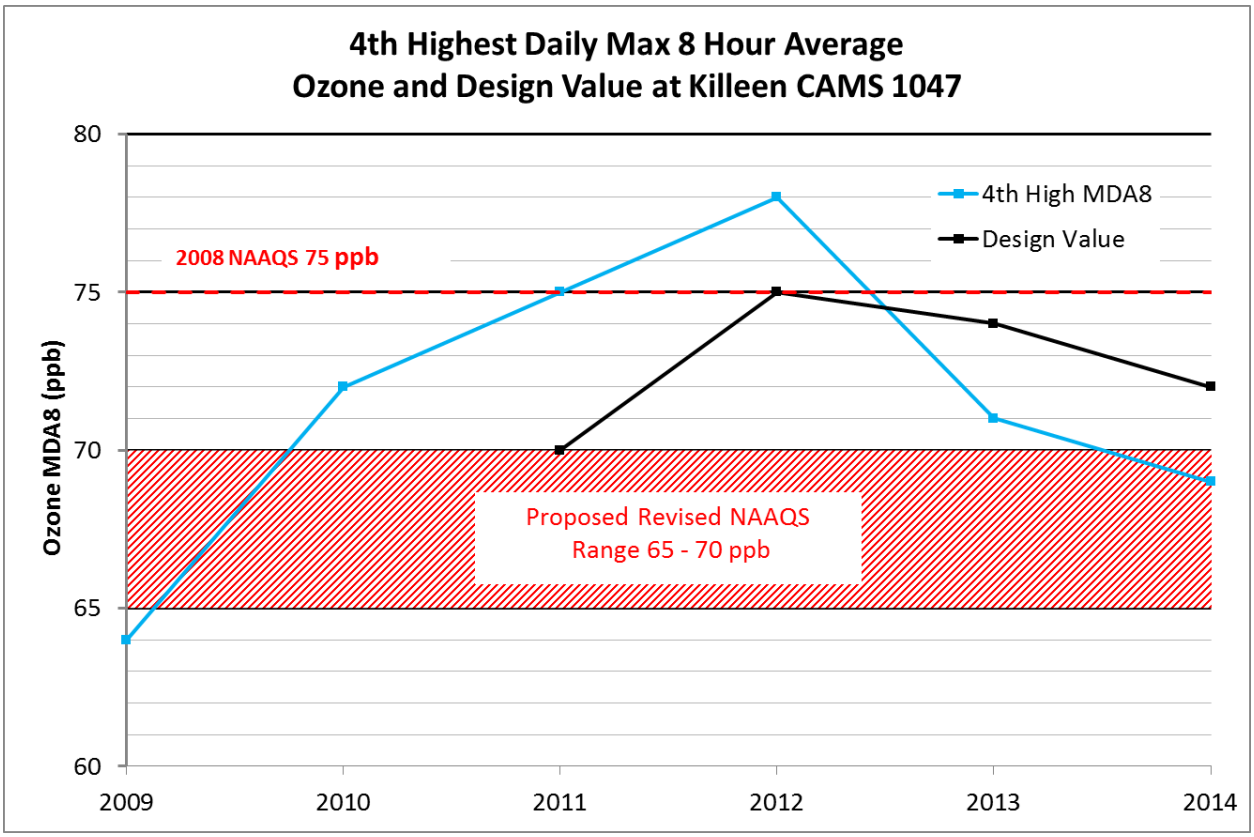

Figure 3-3. 4th Highest MDA8 and Design Values at the Killeen (CAMS 1047) Monitor in relation to the current and proposed NAAQS. The Design Value time series starts in 2011 because 3 years of MDA8 values (2009-2011) are required to calculate the Design Value.

3.3 Annual Trends in 4th High MDA8 Ozone Concentrations for Monitors in the Vicinity of the KTF Area

The analysis of Parker et al. (2013) showed that the Killeen monitor experiences high ozone only during periods of high regional background ozone, and that an additional contribution is usually required from local and/or other nearby Texas sources to cause ozone to reach MDA8≥75 ppb. Given the strong influence of the regional background, we reviewed 2005 – 2014 trends in 4th highest MDA8 ozone concentrations for ozone monitors that are located close to the KTF Area (Figure 3-4). All available data for the Killeen-Skylark monitor and the currently active Temple Georgia as well as the inactive Temple monitor (CAMS 651) are presented. Data are shown for the closest monitor to the north of the KTF Area, (Waco

Mazanec; CAMS 1045), as well as data from monitors that surround the Austin urban area to the south of the KTF Area (Audubon [CAMS 38], Lake Georgetown [CAMS 690], Hutto College St [CAMS 6602] and Round Rock [CAMS 674]). The location of the Waco monitor is shown in Figure 3-6, and the location of the Austin area monitors are shown in Figure 3-7. The Round Rock (CAMS 674) monitor was active for the 2006 – 2010 ozone seasons but was then deactivated, so it is not shown in Figure 3-7 since only the currently active monitors are present in this TCEQ figure. The Hutto College St. (CAMS 6602) monitor came online for the 2011 ozone season and is currently active. The cities of Round Rock and Hutto are located approximately 6 miles from each other and data from these monitors together provides a continuous record of ozone for that area from 2006 to 2014. To indicate the relation between these two monitors they are both shown in green but with different line styles in Figure 3-4. Note that the Lake Georgetown (CAMS 690), Hutto College St (CAMS 6602) and Round Rock (CAMS 674) monitors are non-regulatory monitors, and as such, data from these monitors are not used in defining design values. Data from these monitors are presented here since they are the monitors that are located between Austin and the KTF Area monitors and, during southerly winds, may be affected by the Austin urban plume as it is transported northward towards the KTF Area.

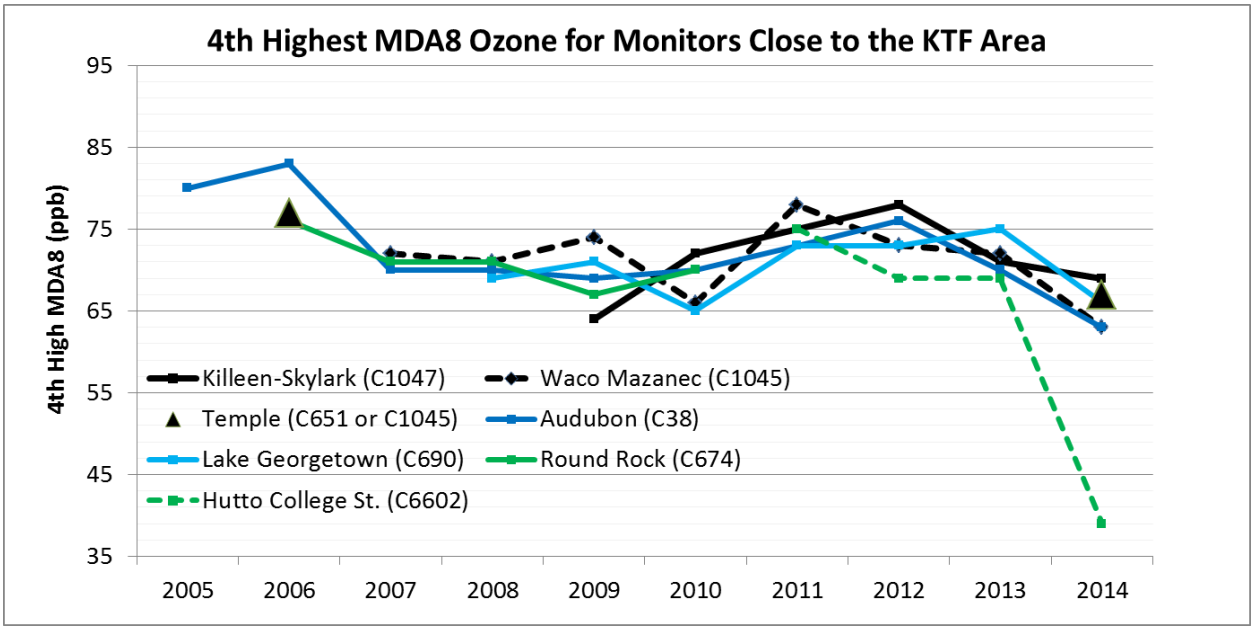

Figure 3-4. 2005 – 2014 4th Highest MDA8 ozone concentrations for ozone monitors close the KTF Area.

The only monitor with a full 10 years of data is the regulatory Audubon (CAMS 38) monitor, shown in dark blue in Figure 3-4. The 4th high MDA8 ozone concentration for this monitor is highest for 2005 and 2006, relatively low for 2007, 2008 and 2009, increases again in 2011 and 2012, then decreases again in 2013 and 2014 and is at its lowest level in 2014. The other monitors' 4th highest MDA8 ozone concentrations are also generally highest in 2011 and 2012 and lowest in 2010 or 2014. The 4th high MDA8 ozone concentration for Hutto College St (CAMS 6602) is far lower than the other monitors' values in 2014. The Hutto monitor had a 4th high MDA8 ozone concentration of only 39 ppb, a 30 ppb decrease from the previous year.

MDA8 values at Killeen are generally comparable in magnitude and variation to the Austin area monitors. In 2009, the Killeen monitor's MDA8 was lower than that of the Austin area monitors. However, during 2010-2014, the Killeen monitor's 4th high MDA8 was higher than that of most of the monitors on the outskirts of the Austin area.

The decrease in 4th high MDA8 ozone concentrations from 2013 to 2014 was smaller at the Killeen monitor (2 ppb decrease), than all the other monitors shown in Figure 3-4. Waco Mazanec reported a 6 ppb decrease, Audubon reported 7 ppb decrease, and Lake Georgetown reported a 9 ppb decrease. The Temple (CAMS 651 and CAMS 1045) monitoring data consists of just two points in Figure 3-4, the values of the 4th high MDA8 ozone concentrations however, are consistent with other regional values and are lower in 2014 than in 2006, consistent with the other monitors.

3.3.1 Annual Ozone Design Value Trends for Large Urban Areas that Influence KTF Ozone

Days with MDA8 ozone concentrations ≥ 75 ppb at the Killeen monitor have been shown to occur during periods when large regions of Texas are also experiencing MDA8 ozone ≥ 75 ppb (Parker et al., 2013). This speaks to the importance of the regional background in causing high ozone days (high ozone is defined here as days with MDA8 ≥ 75 ppb) in the KTF Area. It was also shown by Parker et al. (2013) using ambient data as well as photochemical modeling that the DFW urban plume, the Austin urban plume, and the Waco urban plume all can contribute to high ozone at the Killeen monitor when weather conditions are favorable for transport.

Ozone DVs from three monitors representative of the three urban areas listed above that have the potential to contribute to high ozone at the Killeen monitor, are presented in Figure 3-5, along with the DVs for the monitors in the KTF Area. Note that for Temple, the 4th high MDA8 ozone concentrations are shown as indicators of the DV for that location since 3 years of ozone data are not available, as discussed above.

The Denton (CAMS 56) monitor is northwest of the Dallas Fort-Worth area and is often the monitor recording the highest ozone in the DFW area. Southerly prevailing wind patterns often place Denton downwind of the DFW metro area so that the monitor is heavily influenced by the DFW urban plume. At the end of the 2014 ozone season, the Denton monitor had the highest design value of any monitor in the DFW area. A map showing the location of the Denton monitor is presented in Figure 3-8, with Denton located center north in the Figure. The Austin Northwest (C3) monitor is a regulatory monitor for the Austin region that had the highest DV in the Austin region from 2005-2012. Austin is a currently designated as being in attainment of the NAAQS and no violations of the NAAQS have occurred since EPA made the most recent ozone attainment designations in 2012. The Austin Northwest (CAMS C3) monitor location is presented in Figure 3-7, and the Waco (CAMS 1037) and Killeen monitors are shown in Figure 3-6. The Waco monitor is the only monitor active in the Waco area.

A comparison of the 4 years for which both Waco and Killeen have DVs shows that the Waco DV was 2 ppb higher than the Killeen DV in 2009 but, since then, has been lower than or equal to the Killeen monitor DV. Throughout the time period with ozone monitoring at the Killeen

monitor, the Killeen DVs are within 5 ppb of the Austin DVs, and between 8 to 13 ppb lower than the DFW's Denton monitor DVs. Two annual 4th high MDA8 concentrations at Temple are plotted, one in 2006 from the Temple (CAMS 561) monitor and more recently in 2014 from the Temple Georgia (CAMS 1045) monitor, as indicators of DVs at that location. The Temple monitor annual 4th high MDA8 ozone concentration in 2014 was 67 ppb, which is 5 ppb lower than the Killeen monitor's 2014 design value, and 10 ppb lower than the 2006 Temple 4th high MDA8 value of 77 ppb.

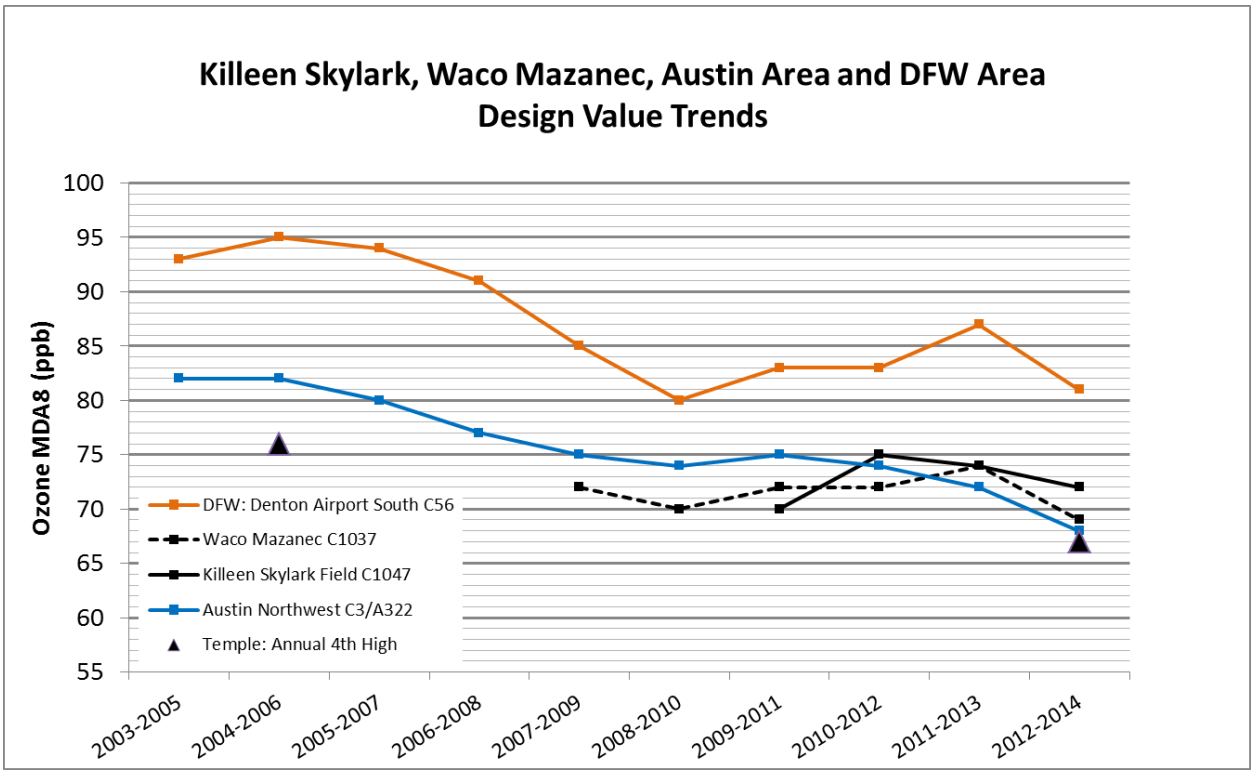

Figure 3-5. Design Values for the Killeen (CAMS 1047; KTF Area), Waco Mazanec (CAMS 1037; Waco area), Austin Northwest (CAMS 3; Austin area) and Denton (CAMS 56; DFW area) monitors.

The Denton and Waco monitor DVs are well-correlated (r=0.90, not shown) during the period when the Waco monitor was operating. It was shown by Parker et al. (2013) that the DFW urban plume affects the Waco monitor more frequently and greater impact than the Killeen monitor; therefore, the Waco and Denton DVs would be expected to show higher correlation than Killeen and Denton DVs. The Waco monitor and the Denton DV both showed generally increasing ozone from 2010 to 2013. During 2012-2014, both the Austin Northwest and Killeen monitors have showed steadily decreasing DVs, with the Killeen monitor DV several ppb higher than that of the Austin Northwest monitor. Given the limited number of years of ozone monitoring data at Killeen, it is difficult to assign significance to these ozone trends. The statistical significance of KTF Area ozone trends may be assessed with greater rigor as additional years of data become available.

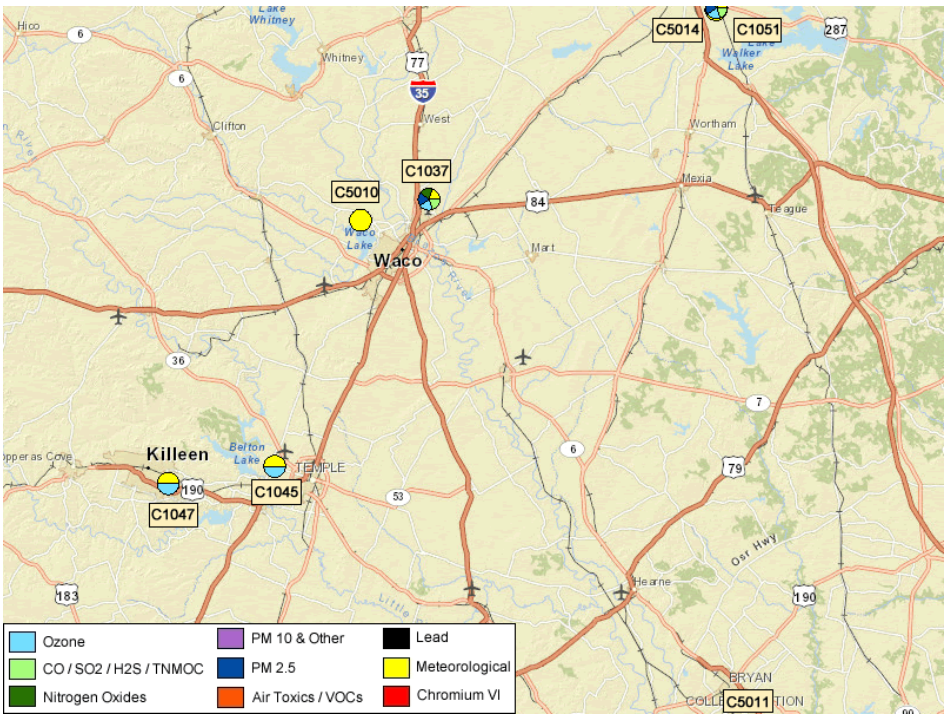

Figure 3-6. KTF Area, Waco area and TCEQ CAMS monitor locations[7].

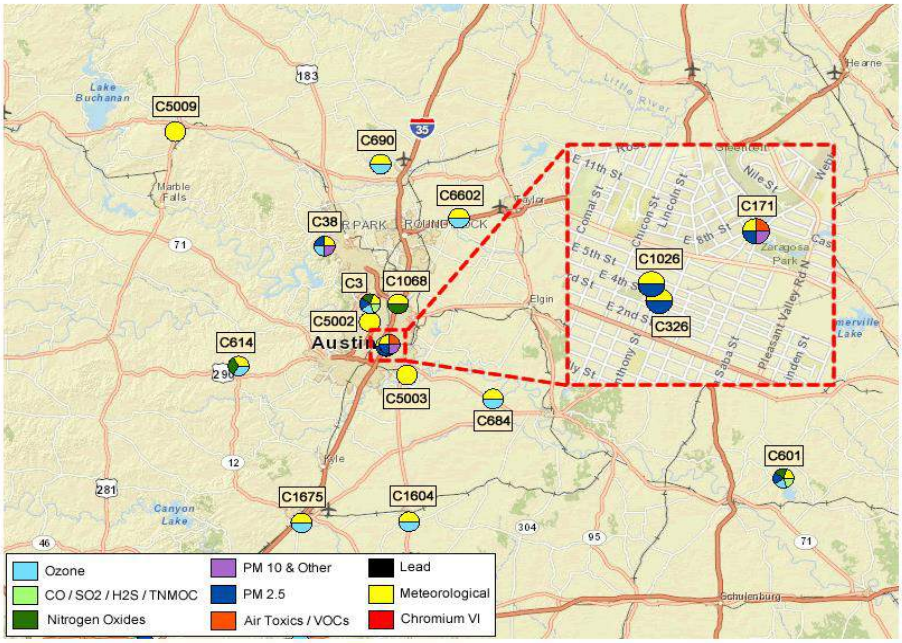

Figure 3-7. Austin area and TCEQ CAMS monitor locations[8].

[7] http://www.tceq.state.tx.us/cgi-bin/compliance/monops/select_summary.pl?region09.gif.

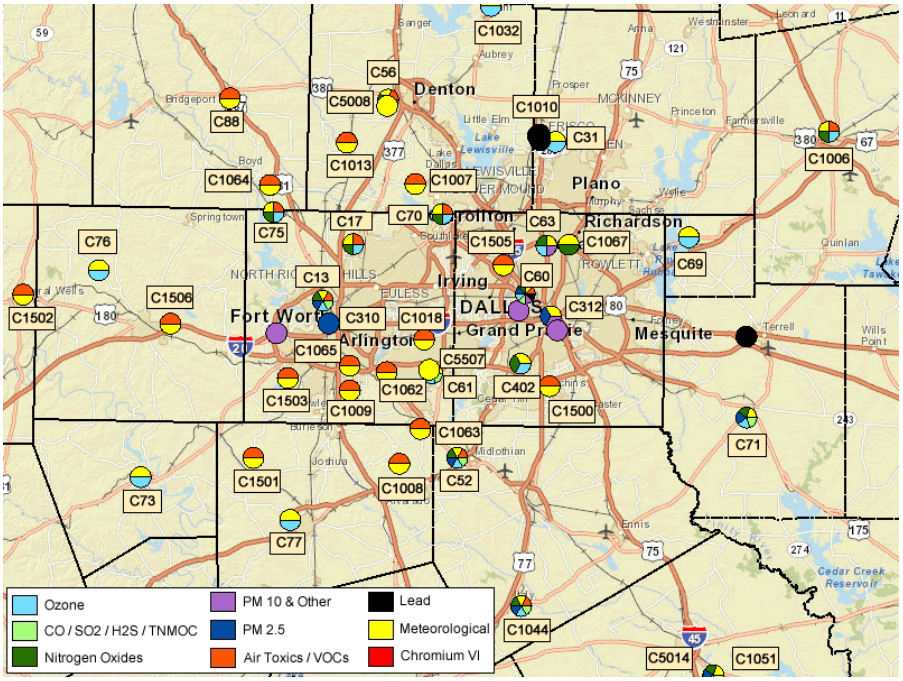

Figure 3-8. DFW area and TCEQ CAMS monitor locations[9].

[8] http://www.tceq.state.tx.us/cgi-bin/compliance/monops/select_summary.pl?region11.gif
[9] http://www.tceq.state.tx.us/cgi-bin/compliance/monops/select_summary.pl?region04.gif.

4.0 EMISSION INVENTORY ANALYSIS

Accurate and up-to-date emission inventories of ozone precursors are a key component of air quality planning. Emission inventories are used to assess the nature of an area's ozone problem and can help answer questions such as whether ozone formation in the region is limited by the amount of available NOx or VOC as well as which types of emissions sources are good candidates for emissions controls that could reduce the area's ozone levels. Emission inventories are also required for ozone modeling. Ozone models are used to gain a better understanding of an area's ozone problem and to test potential impacts of emission control strategies.

Following EPA's 2010 reconsideration of the ozone standard, the TCEQ began preparing for State Implementation Plan (SIP) development by planning for ozone modeling that would coordinate efforts for all Texas Near Non-Attainment Areas (NNAs). The TCEQ developed an emission inventory for a 2006 ozone modeling episode. The purpose of the ozone modeling was to develop and test emissions control strategies that would ensure that each NNA would attain the new ozone standard. The 2006 emission inventory and air quality modeling are now dated and no longer adequately reflect present emission levels due to changes to parameters important to emission inventory development. Examples of these parameters include the amount of oil and gas activity and ongoing changes to on-road vehicles and off-road equipment fleets as a result of fleet turnover and changes in vehicle and equipment populations. The TCEQ has recently developed a 2012 ozone modeling episode for use by the Texas NNAs. This ozone modeling episode will eventually be used for emission control strategy development and evaluation.

The TCEQ selected a June, 2012 episode which will serve as an initial base case modeling episode. The TCEQ plans to eventually expand this modeling episode to include the entire 2012 ozone season. The purpose of the 2012 base case episode is to determine whether the photochemical model is able to replicate observed ozone and precursors during a historical period of high ozone. If the model is able to reproduce the past ozone episode with reasonable accuracy it may then be used to make projections of future year ozone and to evaluate effects of proposed emission control strategies.

The TCEQ recommended that NNAs review emission inventories that may be used for ozone modeling or may be used as the basis for future year emission inventory development. The purpose of this Section is to provide a review of the 2012 TCEQ emission inventories for the KTF Area for biogenic, off-road mobile, on-road mobile, area and point sources. Point sources are large stationary emissions sources that exceed a specified emissions threshold and therefore are tracked individually in the emissions inventory. Area sources are sources that may be spread out geographically and are small individually (such as an oil well), but, taken together, may constitute a sizeable amount of emissions. Off-road mobile source emissions are from mobile and portable internal combustion powered equipment not generally licensed or certified for highway use. Biogenic emissions are emitted by natural sources such as trees, agricultural crops, and microbial activity in soils.

In this Section, we summarize the TCEQ 2012 biogenic and anthropogenic emission inventories for the KTF Area, evaluate emissions trends between 2006 and 2012, examine emissions estimation methodology, and identify emissions categories that are overestimated or underestimated, accompanied by high levels of uncertainty, or for which more accurate or detailed emissions are available.

4.1 All Source Emissions Overview

The TCEQ 2012 emission inventory is summarized below to establish the relative importance of point, area, on-road, and off-road sector emissions in the KTF Area emission inventory. At the time this analysis was performed, 2012 was the most recent year for which a full KTF Area emission inventory (i.e. anthropogenic and biogenic emissions) was available.

Figure 4-1 shows NOx and VOC emissions by source category in the KTF Area for 2012. KTF-wide 2012 total emission estimates are 62 tpd NOx and 1,026 tpd VOC. The largest three emissions source categories, on-road vehicles (23 tpd, 37%), off-road sources (16 tpd, 26%), and biogenic sources (12 tpd, 19%), account for 82% of KTF Area NOx emissions. Point sources (9.2 tpd, 15%) and area sources (2.2 tpd, 4%) sources together account for less than 20% of KTF Area total NOx emissions. Biogenic sources are the largest VOC category comprising 95% (978 tpd) of KTF Area total VOC emissions. Anthropogenic sources account for 5% of VOC emissions with contributions from: area sources (3%, 32 tpd), on-road vehicles (1%, 8.1 tpd), off-road sources (1%, 6.0 tpd), and points sources (<1%, 2.2 tpd).

Biogenic emission estimates for 2012 were developed by the TCEQ using the Model of Emissions of Gases and Aerosols from Nature (MEGAN; Guenther et al., 2012) version 2.10. MEGAN emissions provide hourly, day-specific emissions that depend on photosynthetically active solar radiation and temperature as well as other inputs such as land cover and plant type. Episode average biogenic emissions were calculated from the TCEQ 2012 biogenic emission inventory for the KTF Area[10].

Biogenic NOx emissions contributions in the KTF Area are higher than in other areas of east Texas for which Ramboll Environ has conducted emission inventory reviews (e.g. Grant et al. 2015a; Grant et al., 2015b). This is due, at least in part to intensive agricultural activity in the KTF Area. The nitrogen cycle is the process by which nitrogen is transformed from one form to another through processes such as fixation, ammonification, nitrification, and denitrification. Denitrification is the process by which microorganisms in soil convert nitrate or nitrite molecules into gaseous forms of nitrogen (such as nitrogen oxide; NO). Fertilizer application and the presence of abundant organic material in soil increase the rate of nitrogen cycling in a soil system while soil properties and water content determine the amount of nitrogen released into the atmosphere. Higher temperatures, anaerobic conditions, and water saturation are all factors that increase nitrogen emissions to the atmosphere from soils (Sakulyanontvittaya et al.,

[10] http://www.tceq.texas.gov/airquality/airmod/data/tx2012

2012). Therefore, we expect that agricultural areas where nitrogen-based fertilizers are applied to the soil to have biogenic NOx emissions and that these emissions would increase during periods of hot weather or following heavy rains. In 2012 there were 723,979 planted acres in the KTF Area with three crop types accounting for over 75% of the planted acres: grass (52%), wheat (13%), and corn (11%)[11].

Ozone formation depends on the amount of NOx and VOC present as well as on the ratio of VOC to NOx, where the ratio is taken in terms of parts per billion by carbon (ppbC) per ppb. When the VOC/NOx ratio is higher than about 10, ozone formation is limited by the amount of available NOx and reducing NOx tends to decrease peak ozone concentrations. However, if the VOC/NOx ratio is less than about 7, reducing NOx tends to increase ozone in the vicinity of NOx emission sources (e.g., an urban area) and the area is said to be VOC-limited. In this situation, ozone is suppressed in the urban area due to titration by large amounts of fresh NO emissions. When NOx emissions are reduced, suppression of ozone by NO is lessened and ozone increases.

For the KTF Area, the emission inventory VOC/NOx ratio is 54 ppbC/ppb, which is well within the NOx-limited regime. The presence of abundant biogenic VOC emissions ensures that there are sufficient VOCs to allow ozone formation and that ozone formation is limited by the amount of available NOx. This means local emissions control strategies should focus on reducing NOx emissions.

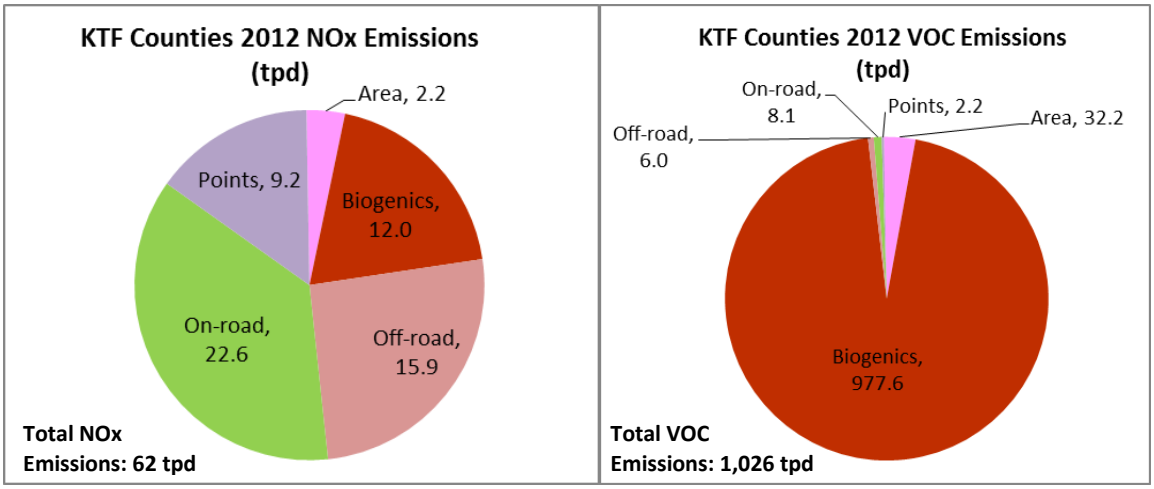

Figure 4-1. 2012 KTF Counties emissions by source category for NOx (left) and VOC (right).

[11] United States Department of Agriculture (USDA) Farm Services Agency (FSA) Crop Acreage Data. 2012 acreage data as of January 2013. http://www.fsa.usda.gov/FSA/webapp?area=newsroom&subject=landing&topic=foi-er-fri-cad

4.2 Anthropogenic Source Emissions Overview

The TCEQ 2012 anthropogenic emission inventory is summarized below to establish the geographical distribution of point source, area source, on-road and off-road emissions from human activities in the KTF Area. Figure 4-2 shows NOx and VOC emissions for 2012 by county for all anthropogenic source categories.

78% of the 2012 KTF Area anthropogenic NOx emissions are from two counties, Bell (45%) and Milam (32%), with contributions from each of the remaining three counties of 7% or less. Point sources make the largest 2012 contribution to the anthropogenic NOx inventory in Milam County (56%). On-road vehicle NOx emissions are the largest contributor to NOx emissions in Bell County (71%) and Coryell County (54%) due to higher populations in Bell and Coryell Counties relative to other counties in the KTF Area, and in Bell County due to the presence of the heavily-trafficked interstate highway I-35. Off-road equipment emissions are the largest contributor to NOx emissions in Lampasas County (51%), Mills County (68%), San Saba County (62%), and Hamilton County (66%). Milam County and Bell County are the only counties with point source emissions; the remaining counties have no point source emissions in 2012. Across all KTF counties, 45% of the anthropogenic NOx emissions are from on-road vehicles, 32% are from off-road sources, 18% are from point sources, and 4% are from area sources.

A majority of the 2012 KTF Area anthropogenic VOC emissions (66%) are from area sources. Bell County (51%) and Milam County (32%) together account for 82% of the VOC emissions from anthropogenic sources in the KTF Area. The remaining 18% of the VOC emissions are emitted in Coryell County (7%), Lampasas County (4%), Hamilton County (3%), San Saba County (1%), and Mills County (1%). Area sources are the largest and majority source of anthropogenic VOC emissions for each county in the KTF Area, contributing between 52% and 92% of each county's anthropogenic VOC emissions. On-road vehicles are the second largest source of VOC emissions (4% to 27% of VOC emissions) in all counties except Lampasas County, for which off-road emissions (24% of VOC emissions) are the second largest source. KTF Area-wide anthropogenic VOC emissions by source are as follows: area sources (66%), on-road vehicles (17%), off-road sources (12%), and point sources (5%).

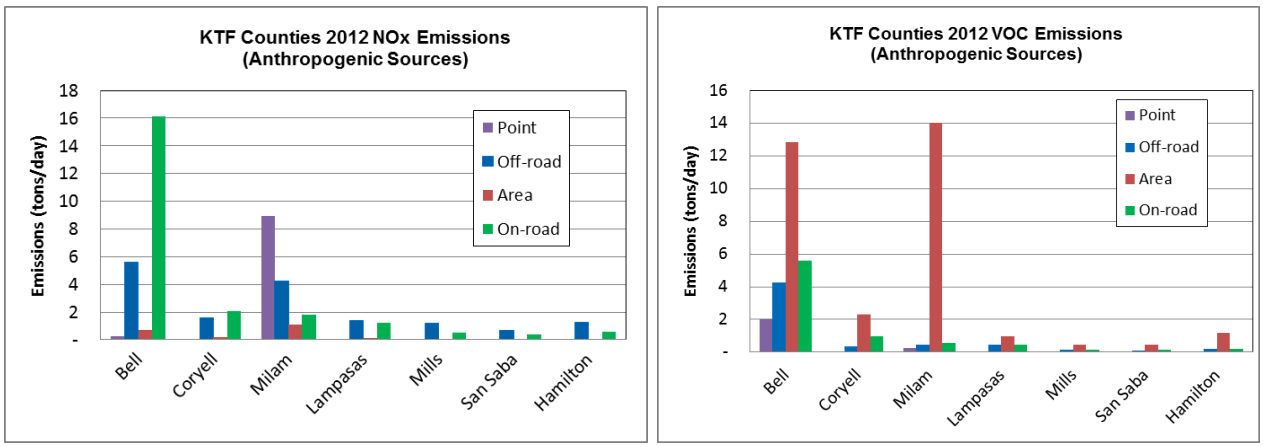

Figure 4-2. KTF Counties 2012 anthropogenic emissions by sector for NOx (left) and VOC (right).

4.2.1 Fort Hood

The Fort Hood military post warrants additional discussion because it is one of the largest military installations in the United States[12] and may have sizable emissions in all source categories of anthropogenic emissions. Fort Hood occupies 335 square miles in Bell and Coryell Counties[12] (see Figure 1-4), and is the only post in the United States capable of stationing and training two Armored Divisions[12]. In 2011, Fort Hood had population of 47,190 army military and army civilian personnel (United States Army Environmental Command (USAEC), 2014). Based on the army force structure realignment, there are maximum anticipated personnel reductions at Fort Hood of 16,000 by 2020; if the maximum personnel reductions were made, this would lead to a 2020 combined army military and army civilian personnel population at Fort Hood of 31,190[12].

Fort Hood includes the Military Equipment and Training Site (MATES) where 850 pieces of heavy equipment are stored and supported. Additionally, 1,700 pieces of equipment are stored and supported at an Equipment Concentration Site (ECS) at Fort Hood[12]. Equipment at the MATES and ECS is expected to be a source of ozone precursor emissions; the magnitude of emissions depends on equipment characteristics as well as frequency and duration of equipment use.

In 2005, the Texas Department of Transportation (TXDOT) commenced a project to widen state Highway 195 from Fort Hood to Georgetown, Texas[12] in order to facilitate transportation between Fort Hood and seaports on the Gulf of Mexico. The first phase of this project was the widening of SH 195 from Killeen south to the community of Ding Dong, TX. The second phase is scheduled for completion in 2016 and extends four lane continuity on SH 195 south to Georgetown in Williamson County. Upon completion, the expansion will provide an

[12] Fort Hood Fact Sheet No. 0703, http://www.hood.army.mil/facts/FS%200703%20-%20Fort%20Hood%20Overview.pdf

uninterrupted four lane, interstate quality highway from Fort Hood to IH-35 and on to Texas' Gulf Coast ports. The widening of SH 195 has the potential to both increase vehicle traffic and associated ozone precursor emissions in western Bell County.

Due to its status as a military base, Fort Hood's emissions may not be well-characterized in the TCEQ's 2012 emission inventory. On-road emission inventories that TCEQ has developed rely on vehicle miles traveled (VMT) estimates from the Highway Performance Monitoring System (HPMS) managed by the Texas Department of Transportation (TxDOT) that cover public roads only. According to the Federal Highway Administration HPMS Field Manual, "All roads open to public travel are reported in HPMS regardless of ownership, including Federal, State, county, city, and privately owned roads such as toll facilities."[13] If a roadway is within the Fort Hood fence line and is not open to public travel, then the emission estimates from that roadway would not be included in the TCEQ on-road emission inventory. While the HPMS data would capture trips to/from the Fort Hood military facility, it does not capture driving activity on roads not open to the public in the facility (TCEQ, 2015a). We therefore expect that on-road emissions from Fort Hood are underestimated in the TCEQ's emission inventories. In subsequent sections of this report, we discuss the characterization of Fort Hood off-road, area, and point source emissions in the TCEQ 2012 inventory.

Figure 4-3. Fort Hood area (shaded brown) with county boundaries. I-35 is shown in red.

[13] http://www.fhwa.dot.gov/policyinformation/hpms/fieldmanual/

4.3 2006 to 2012 Emission Trends

The TCEQ 2006 and 2012 anthropogenic emission inventories are compared below to evaluate KTF Area emissions trends between 2006 and 2012. Figure 4-4 shows anthropogenic NOx and VOC emissions by source category in the KTF Area for 2006 and 2012. KTF Area-wide anthropogenic NOx emissions decreased from 90.2 tpd in 2006 to 49.9 tpd in 2012 (-45%). All anthropogenic NOx emissions source categories showed decreases from 2006 to 2012: point source NOx emissions decreased by 23 tpd (-72%), on-road vehicle NOx emissions decreased by 11 tpd (-32%), area sources by 0.9 tpd (-30%), and off-road mobile sources by 5.6 tpd (-26%). KTF Area-wide anthropogenic VOC emissions decreased by less than 1% from 2006 (48.6 tpd) to 2012 (48.5 tpd). The following anthropogenic VOC emissions source categories decreased from 2006 to 2012: point source VOC emissions decreased by 2.7 tpd (-55%), on-road vehicles by 2.4 tpd (-23%), and off-road equipment by 0.5 tpd (-8%); area source VOC emissions increased by 5.5 tpd (21%) from 2006 to 2012.

Changes to on-road emissions result from changes in vehicle activity (VMT) and fleet turnover to cleaner vehicles over time that is mandated by Federal regulations. VMT activity trends are typically consistent with human population trends. KTF Area population increased by 13% from 2006 to 2012 (see Table 4-5); decreases in NOx and VOC emissions from on-road vehicles are therefore likely the result of fleet turnover to new vehicles between 2006 and 2012 rather than decreases in vehicle activity. Similar to on-road vehicles, changes in emissions from off-road sources are the result of both changes in activity (i.e. equipment population and annual use) and fleet turnover to newer equipment. Decreases in off-road NOx and VOC emissions from 2006 to 2012 are likely the result of fleet turnover to newer, cleaner burning equipment between 2006 and 2012 rather than decreases in off-road activity. Changes in area source emissions from 2006 to 2012 are likely due to a combination of factors: oil and gas activity increases from 2006 to 2012 (effect is to increase emissions), improvements in TCEQ's oil and gas area source emissions estimation methodology (effect varies depending on source category), and increases in human population from 2006 to 2012 (effect is to increase emissions).

Point source emission decreases from 2006 to 2012 are due primarily to decreases in emissions from the Sandow Generating Station. The TCEQ 2006 modeling files indicated that Unit 4 was the only Sandow Generating Station unit online in 2006 subject to continuous emission monitoring (CEM) and reporting hourly emissions to the EPA's Acid Rain Database. Unit 5 was not built until 2009. Units 1, 2, and 3 were reported as being shutdown in late 2006[14] which is inconsistent with the lack of emissions for Units 1, 2, and 3 in the TCEQ's June 2006 emission inventory; the lack of 2006 emissions from these units indicates that they were also offline during June 2006.

[14] http://www.rockdalereporter.com/news/2010-01-07/Local_News/DECADE_IN_REVIEW.html

Biogenic VOC and NOx emission estimates differed considerably between 2006 and 2012. In 2006, KTF Area total biogenic NOx emissions were 3.2 tpd and biogenic VOC emissions were 1843 tpd. However, both the 2006 and 2012 inventories show a large amount of biogenic VOC emissions indicative of a NOx limited ozone formation regime. The 2006 VOC/NOx ratio is 67 ppbC/ppb, which is well within the NOx limited regime, as is true for the 2012 KTF Area emission inventory. Differences in biogenic emissions between 2006 and 2012 are likely related to differences in the MEGAN model configuration and input data and differences in meteorological conditions for the 2006 and 2012 episodes.

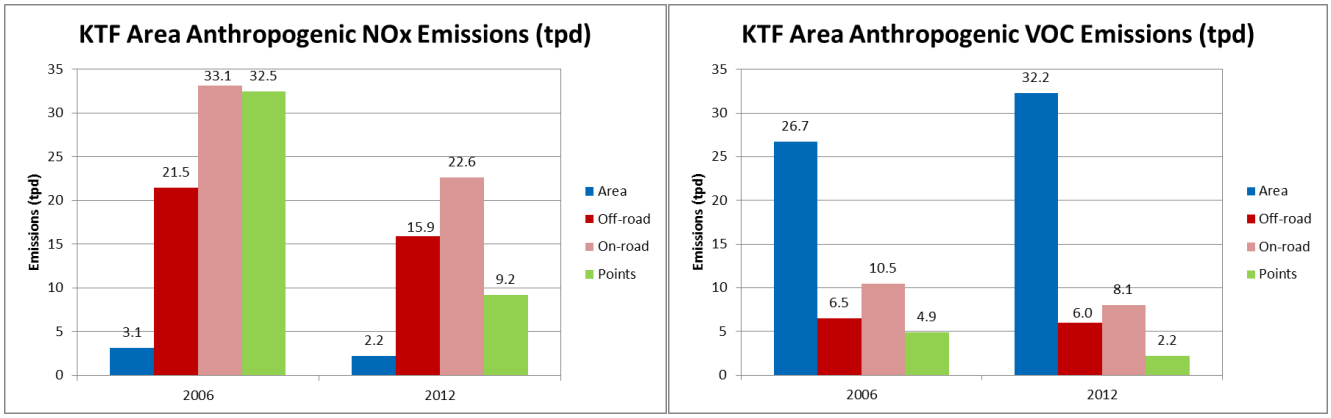

Figure 4-4. KTF Area 2006 and 2012 anthropogenic emissions by sector for NOx (left) and VOC (right).

4.4 Off-Road Emissions Review

Off-road mobile source emissions are from mobile and portable internal combustion powered equipment not generally licensed or certified for highway use. Off-road emissions equipment categories span a wide range of equipment types such as lawn and garden equipment, heavy-duty construction equipment, aircraft and locomotives. Off-road emissions for many of these categories are calculated using EPA's NONROAD computer model. TCEQ has developed a Texas-specific application of the NONROAD model called TexN (ERG, 2014) for counties within Texas and this model is described below.

4.4.1 Overview of emissions inventory

Ramboll Environ obtained the most recent 2012 off-road emission inventory for the KTF Area from several sources based on input from TCEQ staff (TCEQ, 2014a). The most recent source of data available for each emissions source category was used. Table 4-1 contains a listing of data sources. The KTF Area off-road source emissions by county and source category are presented in Appendix A.

Table 4-1. 2012 off-road emission inventory data sources.

Off-road Type	Emissions Data Source
Locomotives[b]	Source: TCEQ ftp site ftp://amdaftp.tceq.texas.gov/pub/ Reference: No reference available[a]
Drill Rigs[b]	Source: Personal communication with TCEQ staff (TCEQ, 2014b) Reference: ERG (2011) methodology with 2012 spudding activity
Aviation[b,c]	Source: TCEQ ftp site ftp://amdaftp.tceq.texas.gov/pub/ Reference: ERG (2011b)
Other Off-road Equipmentc[d]	Source: TCEQ ftp site ftp://amdaftp.tceq.texas.gov/pub/ Reference: TexN model, version 1.6.1 (ERG, 2014)

[a] Previously based on ERG (2010b). Emissions have been updated, but new documentation is not yet available.
[b] Average day emissions available from TCEQ were used.
[c] Includes aircraft and airport ground support equipment
[d] Average day emissions were estimated based on weekday, Saturday, and Sunday emissions available from TCEQ according to the following equation: (weekday emissions*5 + Saturday emissions + Sunday emissions)/7.

The off-road sector is made up of various types of equipment that change locations at least once each year (or in certain cases once each season). Off-road sector emissions for many types of off-road equipment can be estimated with the U.S. EPA's NONROAD model[15]. A Texas non-road emissions model, the TexN model (ERG, 2014) is also available. The TCEQ developed the TexN model which runs the NONROAD model with Texas-specific data for equipment activity parameters such as equipment population, equipment annual hours of activity, seasonal usage patterns, and activity growth to the extent that such Texas-specific data is available, primarily from TCEQ-funded studies as described in ERG (2008b) and ERG (2014). The TexN model is described in more detail in Section 2.2.1. Off-road sources not in the TexN model (locomotives,

[15] http://www.epa.gov/otaq/nonrdmdl.htm

drill rigs, and aviation) are estimated in stand-alone analyses based on the unique types of engines and activities associated with each of these off-road sources.

Figure 4-5 and Figure 4-6 show 2012 off-road emission contributions by source category for the KTF Area for NOx and VOC. The three largest contributors to off-road NOx emissions are agricultural equipment (50%), locomotives (32%), and construction and mining equipment (11%). The top three NOx emissions sources are all primarily made up of diesel engine fleets and together account for 93% of off-road source NOx emissions. 70% of VOC emissions are from pleasure craft (27%), recreational equipment (23%), and lawn and garden equipment (20%). Off-road source categories with the largest contributions to VOC emissions have gasoline engine fleets.

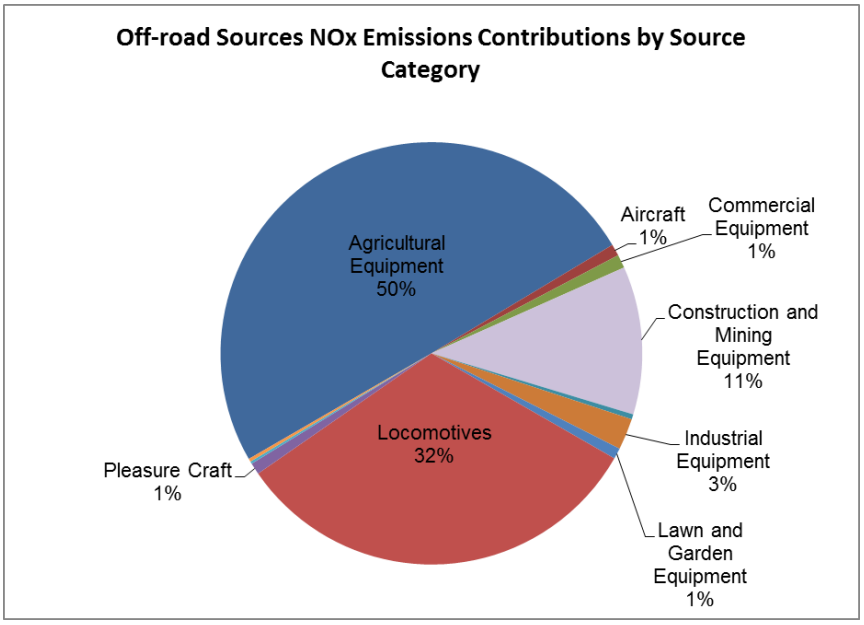

Figure 4-5. KTF Counties 2012 off-road NOx emissions emission by source category.

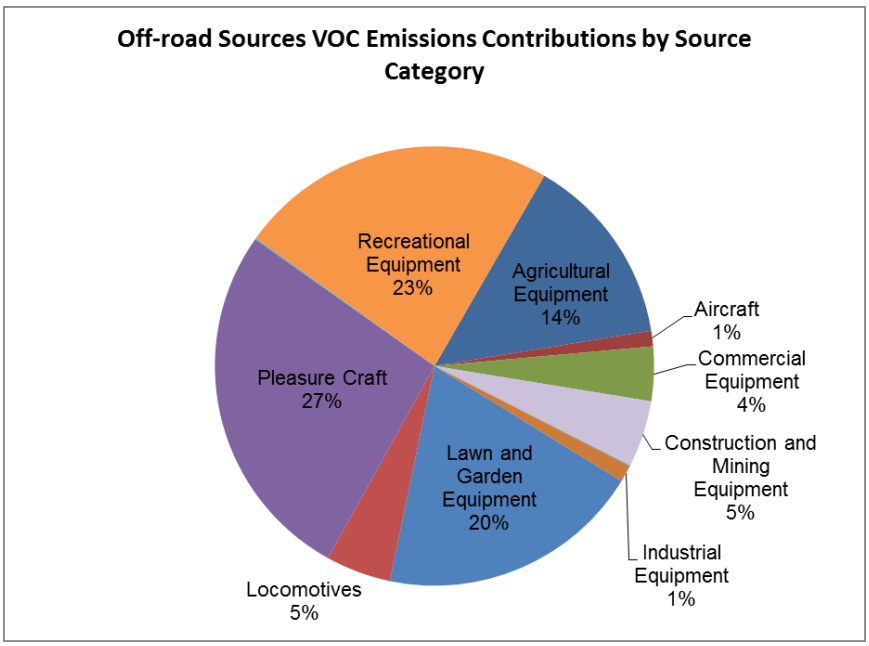

Figure 4-6. KTF Counties 2012 off-road VOC emissions emission by source category.

Table 4-2 shows contributions by county of NOx and VOC to off-road emissions. The counties that have the highest off-road source NOx emissions are Bell (35%) and Milam (27%); agricultural equipment (34%), locomotives (34%), and construction and mining equipment (20%) are the highest contributors to NOx emissions in Bell County while locomotives (48%) and agricultural equipment (44%) are the largest contributors in Milam County. Coryell, Hamilton, Lampasas, Mills, and San Saba Counties together contribute 38% of the KTF Area NOx emissions. The county that has the highest off-road VOC emissions is Bell County (72%). Bell County has the highest pleasure craft, recreational equipment, and lawn and garden equipment emissions in the KTF Area.

Table 4-2. KTF Area 2012 off-road emissions by county.

County	NOx		VOC	
	Emissions (tpd)	Percent of Total	Emissions (tpd)	Percent of Total
Bell	5.57	35%	4.28	72%
Coryell	1.59	10%	0.35	6%
Hamilton	1.27	8%	0.18	3%
Lampasas	1.37	9%	0.47	8%
Milam	4.26	27%	0.47	8%
Mills	1.17	7%	0.13	2%
San Saba	0.67	4%	0.11	2%
KTF Total	**15.89**	**100%**	**5.98**	**100%**

4.4.2 Analysis

4.4.2.1 Off-Road Equipment Emissions Calculated Using the TexN Emission Model

All off-road emissions except for emissions from locomotives, aircraft, and drilling equipment are estimated in the TexN model; TexN model sources taken together represent 67% of off-road NOx emissions and 94% of off-road VOC emissions in the KTF Area.

The TexN model includes input data that has been updated to more accurately reflect Texas specific off-road operations as well as NONROAD default data. There have been a number of emission inventory improvements in TexN which are typically made on a category-by-category basis and consist of updates to the state-wide equipment population, spatial allocation of population, temporal allocations, and/or annual hours of use estimates.

For those equipment types for which NONROAD default data is used, there is considerable uncertainty in emissions that are calculated with TexN. NONROAD model default base year state-wide population estimates were developed based on nationwide population estimates allocated to the state level using spatial surrogates. National equipment populations were developed from calendar year 1996 to 2000 base year data. Growth rate estimates used to project population to past and future years were estimated for most source categories based on population trends taken from EPA's analysis of 1989 to 1996 nationwide population data (exceptions are off-road motorcycles, ATVs and snowmobiles) (EPA, 2004); a notable exception is construction equipment population growth rates which were estimated based on Texas-specific data in ERG (2014).

The TexN model includes Texas-specific non-default estimates of growth rates for most diesel construction equipment types. TexN also includes Texas-specific temporal allocations which may differ from NONROAD region-specific default temporal allocations. Because of the distributed nature of off-road equipment across residential, commercial and industrial sectors, updating NONROAD model inputs can be resource-intensive. The TCEQ has funded a series of studies that have developed detailed Texas-specific data for use in TexN as described in ERG (2008b) and ERG (2014). Table 4 below summarizes data sources used in the TexN model for the KTF Area. Below, we discuss source categories that make the largest contributions to the KTF Area off-road NOx emission inventory and describe more detailed non-default data for the KTF Area that were available within TexN.

Table 4-3. Non-default data used in the TexN model for the KTF Area (ERG, 2008b).

Equipment Type	State-wide Population	Spatial Allocation (of population)	Temporal Allocation	Annual Hours of Use
Construction and Mining	Non-default[1]	Non-default[1]	Non-default[1]	Non-default[1]
Agricultural	Non-default	Non-default	Non-default	Non-default
Industrial	D	D	D	D
Commercial	D	D	D	D
Lawn and Garden	Non-default[2]	Non-default[2]	D	Non-default[2]
Logging	D	D	D	D

Equipment Type	State-wide Population	Spatial Allocation (of population)	Temporal Allocation	Annual Hours of Use
Pleasure Craft	Non-default	Non-default	D	D
Recreational	D	D	D	D
Railroad	D	D	D	D
Airport Ground	3	D	D	D

[D] NONROAD model default data used.
[1] Local data limited to diesel powered construction equipment greater than 25 horsepower.
[2] Local data limited to commercial lawn and garden equipment.
[3] No population estimates provided in TexN.

4.4.2.2 Agricultural Equipment

In a 2009 study (Thesing, 2009) data on agricultural equipment use were gathered from Texas farming operation owners via a telephone survey; these data were used to improve representation of equipment populations, annual hours of use, and seasonal, weekly and diurnal activity profiles for agricultural equipment within TexN. Because of the Texas-specific update to agricultural data within TexN that includes KTF Area specific survey data, improvements to this category are not recommended.

A comparison of the KTF Area 2012 planted acres and agricultural equipment emissions is shown in Table 4-4 below. The emissions distribution of agricultural equipment appears to be generally consistent with the distribution of planted crop acres.

Table 4-4. Comparison of KTF Area 2012 planted acres and agricultural equipment emissions.

County	Planted Area		Emissions (tons/day)		Percent of Total Emissions	
	Acres	Percent of Total Acres	NOx	VOC	NOx	VOC
Bell	147,933	20%	1.89	0.21	24%	24%
Coryell	146,046	20%	1.24	0.14	16%	16%
Hamilton	62,583	9%	1.20	0.12	15%	15%
Lampasas	18,020	2%	0.47	0.05	6%	5%
Milam	239,948	33%	1.85	0.20	23%	24%
Mills	72,231	10%	0.73	0.07	9%	9%
San Saba	37,218	5%	0.52	0.05	7%	6%
Totals	**723,979**	**100%**	**7.90**	**0.84**	**100%**	**100%**

4.4.2.3 Pleasure Craft

TCEQ 2012 emission inventory estimates show pleasure craft emissions only in Bell County which is consistent with the 2011 National Emission Inventory (NEI)[16]. This is reasonable considering that Bell County contains Belton Lake and Stillhouse Hollow Lake, the two significant bodies of water used for recreational boating in the KTF Area.

4.4.2.4 Recreational Equipment

97% of the KTF Area recreational equipment emissions are from all-terrain vehicles (ATVs) and motorcycles. 79% of recreational equipment VOC emissions are from Bell County. Much of the ATV and motorcycle activity is expected to occur in recreational areas around Belton Lake in Bell County, including at the Fort Hood Recreation Area. 20% of recreational equipment VOC emissions are from Lampasas County, although major public use areas for ATVs and motorcycles were not found in Lampasas County.

4.4.3 Off-Road Equipment Emissions Calculated Outside of the TexN Emission Model

4.4.3.1 Locomotives

Line-haul locomotive emissions are reasonable based on expected and actual close agreement between the 2011 NEI and 2012 TCEQ emission inventory at both the area-wide and county levels. Figure 4-7 shows a map of the KTF Area railroads. Counties with multiple railroads and with longer stretches of railroad lines have higher emissions than counties with only one railroad and/or smaller lines. Milam and Bell Counties are the two largest contributors to locomotive emissions, representing a combined 77% of NOx emissions from locomotives in the KTF Area. Both Milam County and Bell County have long stretches of BNSF and UP rail lines. Hamilton County is the only county in the KTF Area that does not have any railroad activity or emissions. Therefore, the emissions distribution is consistent with rail line locations.

Emissions associated with switching locomotive activity at rail yards in Bell and Lampasas Counties represent 7% of KTF Area locomotive emissions in the 2012 TCEQ emission inventory, but there are no emissions in the 2011 NEI from switching locomotives in the KTF Area. “Switching” is the process of sorting and re-combining rolling stock at a rail yard. In the TCEQ 2012 inventory, switching locomotive emissions present in Bell and Lampasas Counties are consistent with the presence of the BNSF Temple Railyard in Bell County and a smaller interchange in Lometa in Lampasas County.

[16] http://www.epa.gov/ttnchie1/net/2011inventory.html

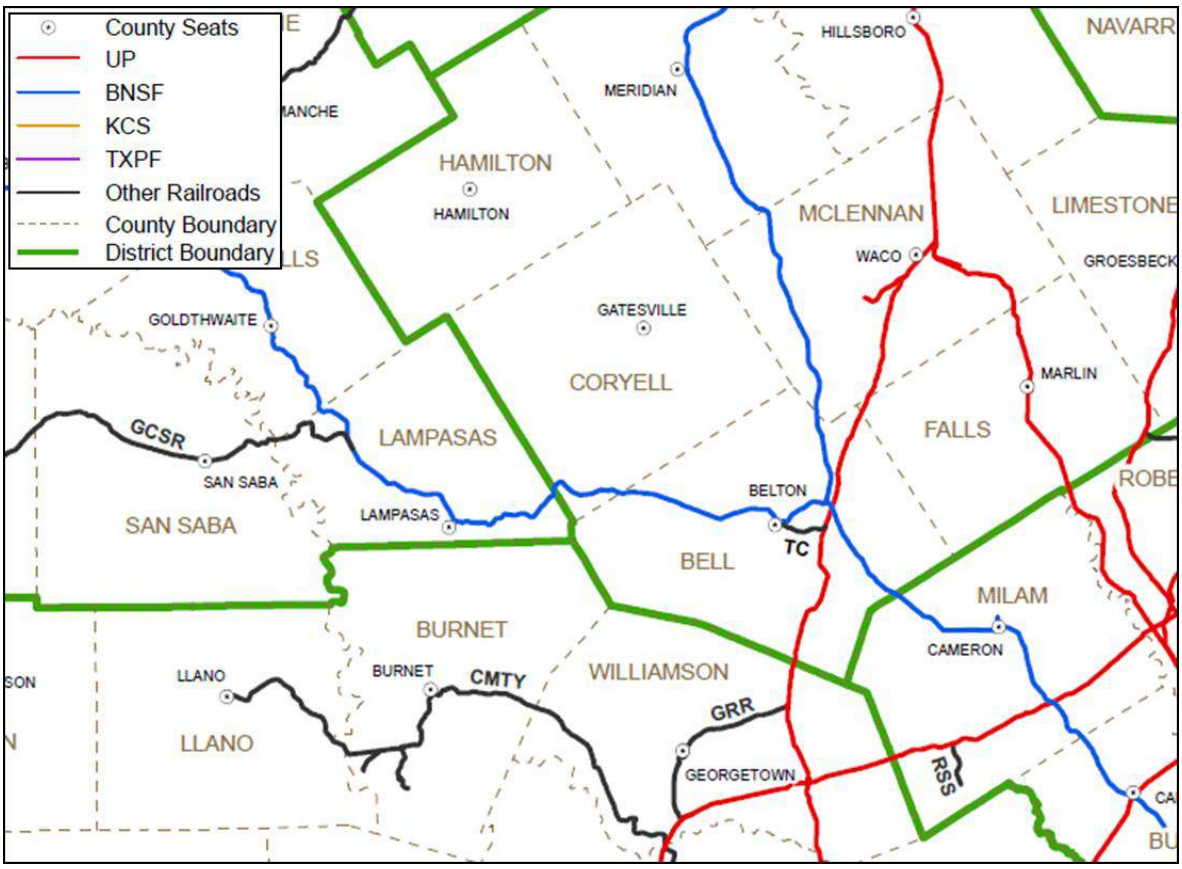

Figure 4-7. Map showing the railroads present in KTF Counties

4.4.3.2 Fort Hood Off-Road Equipment Emissions

Military aircraft emissions are included in emission estimates for the Killeen–Fort Hood Regional Airport which is a military/commercial joint-use facility. The TexN model estimates county-level equipment populations for many types of off-road equipment (e.g. construction, agricultural, lawn and garden equipment) based on various studies as described in TexN model User Guides (ERG, 2008b; ERG, 2014). Off-road equipment emissions estimated in TexN do not include any military equipment such as tanks, armored vehicles, or helicopters, nor are there any equipment populations based on Fort Hood military post activity separate from the county-level estimates included in the TexN model (TCEQ, 2015a). Fort Hood off-road equipment emissions are not well-characterized and may be underestimated.

4.4.4 Area Source Emissions Review

The area source inventory treats in aggregate all stationary sources that have emissions below the point source threshold. These are sources that may be spread out geographically and are small individually, but taken together, may constitute a sizeable amount of emissions. Examples of area sources include dry cleaners, residential wood heating, auto body painting, fires, oil and gas wells and consumer solvent use. These emissions are typically estimated and reported as county totals and allocated to a finer geographic scale using a surrogate such as population distribution. For example, if a certain amount of VOC emissions are allocated to dry cleaners in

a given county most of those emissions would be allocated to the locations within the county that have the highest population density.

4.4.4.1 Overview of Emissions Inventory

Ramboll Environ obtained the most recent available 2012 area source emission inventory for the KTF Area from the TCEQ ftp site (TCEQ, 2014a). For non-oil and gas area sources, emissions were available for a typical weekday, Saturday, and Sunday. Average day emissions were estimated by source classification code (SCC) as: (weekday emissions x 5+ Saturday emissions + Sunday emissions) / 7. Oil and gas area source emissions were available in units of tons per average ozone season day. KTF Area source emissions by county and source category are presented in detail in Appendix A.

The area source sector is made up of various types of stationary sources that fall below point source permitting thresholds. Typically, area source emissions are estimated based on EPA AP-42 methods[17]. For certain area source categories such as consumer products, human population or a related surrogate such as housing units is the typical emissions activity surrogate. KTF Area human population by county is provided for reference in Table 4-5. From 2006 to 2012, human population in the KTF Area increased by 13%. Bell County comprises approximately two thirds and Coryell County comprises close to 20% of KTF Area-wide human population in both years; the remaining counties each account for 6% or less of KTF Area human population. The Figure 1-1 depiction of the major KTF Area urban population areas of Killeen at the border of Bell and Coryell Counties and Temple in Bell County is consistent with the population estimates reported in Table 3-1 which show Bell and Coryell Counties as the most populous counties in the KTF Area.

Table 4-5. Population in the KTF Area in 2006 and 2012 in. Data source: http://www.dshs.state.tx.us/chs/popdat/default.shtm

Counties	2006	2012	Percent Change
Bell	269,073	322,817	20%
Coryell	76,007	77,462	2%
Hamilton	8,480	8,644	2%
Lampasas	20,461	20,171	-1%
Milam	25,618	25,240	-1%
Mills	5,240	5,038	-4%
San Saba	6,102	6,285	3%
Total	**410,981**	**465,657**	13%

Area source oil and gas emissions are significant sources of VOC and NOx emissions due to the number of oil and gas wells in the KTF Area. Texas state oil and gas basins have been defined in

[17] http://www.epa.gov/ttn/chief/ap42/

a number of TCEQ-funded emission inventory studies (ERG, 2010a; ERG, 2012) as shown in Figure 3-1. The oil and gas basins for KTF Area counties were defined as follows:

- Bend Arch-Fort Worth/Barnett Shale: Coryell, Hamilton, Mills, Lampasas, San Saba
- Western Gulf: Bell
- Eagle Ford Shale: Milam

In the KTF Area, only Milam County is within the Eagle Ford Shale formation (see Figure 3-2). As of April 2, 2015, only a very small number of Eagle Shale wells have been completed in Milam County.

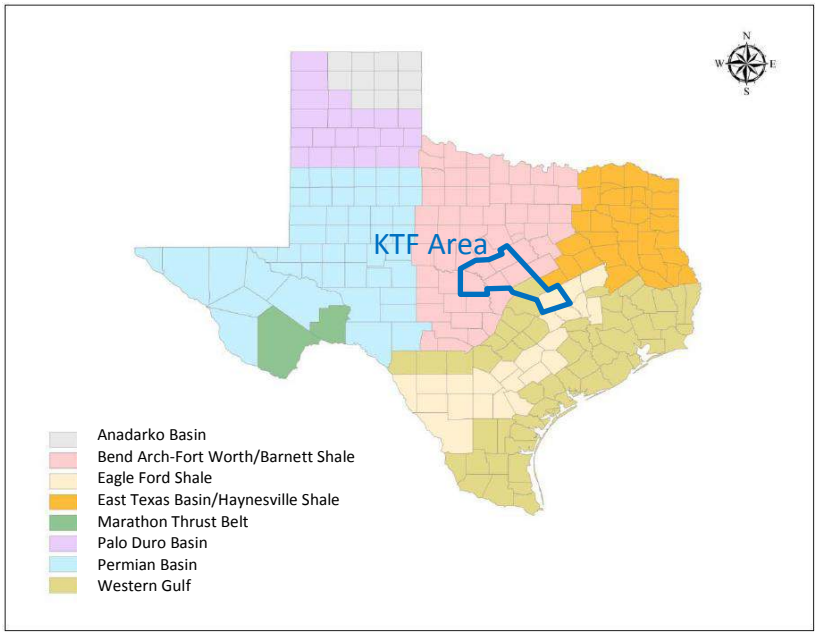

Figure 4-8. Texas Oil and Gas Formations (adapted from ERG, 2012).

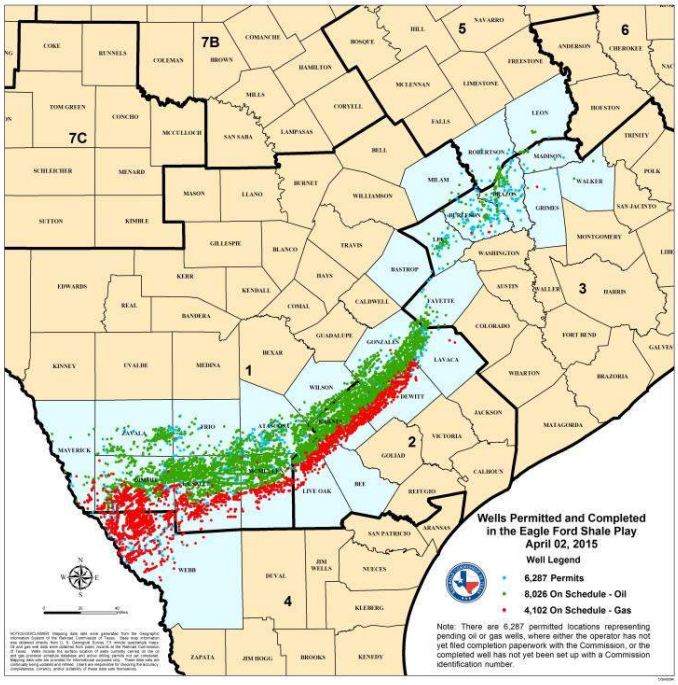

Figure 4-9. Eagle Ford Shale Formation[14].

As shown in Figure 4-10, as of 2014, there were over 1,800 total active oil and gas wells in the KTF Area. These wells produce approximately 458 million cubic feet (MMCF) of natural gas and 616 thousand barrels of oil annually[18]. From 2006 to 2014, 97% or more of the active wells in any given year were oil wells. Close to 100% of all liquid hydrocarbon production in the KTF Area was from oil wells during the 2006 to 2014 period (see Figure 3-3). During the same time period, natural gas production from gas wells accounted for between 32% and 44% and casinghead gas production from oil wells accounted for between 56% and 68% of gas production, annually (see Figure 3-4). During the same time period, Milam County accounted for almost all of the oil and gas activity in the KTF Area comprising 98% or more of the total well count, 99% or more of total oil production and 69% to 76% of total gas production.

The KTF Area gas well count was stable (between 24 and 27 active wells) from 2006 to 2012, increasing to 33 gas wells in 2014. A spike in condensate and natural gas production is noted in 2012, coinciding with the addition of the new wells, with a relatively quick return to pre-2012 gas production levels and decline. KTF Area oil well count was stable (between 901 and 1,075 wells) from 2006 to 2012. Oil well count increased to 1,228 wells in 2013 and 1,732 wells in 2014, potentially due to oil prices that favored development. Consistent with oil well count trends, oil production was stable from 2006 to 2011. Oil production increased in 2012, and

[18] http://www.rrc.state.tx.us/

then leveled off in 2013 and decreased slightly in 2014. Casinghead gas production shows steady, gradual decline from 2006 to 2011, with an increase in 2012, then a resumption of declines to 2013 and 2014.

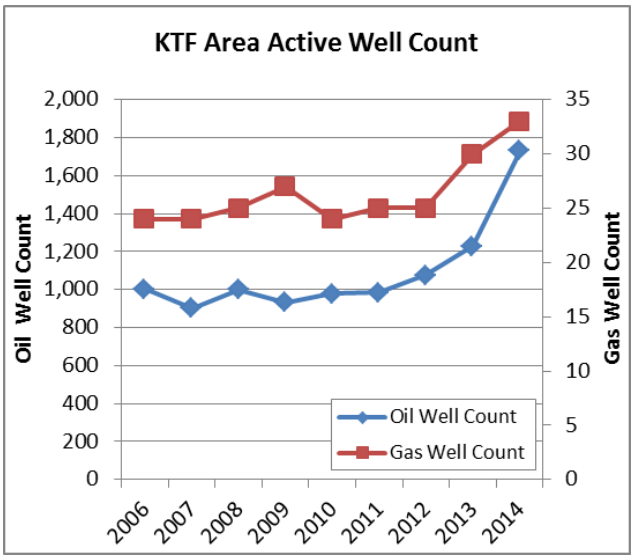

Figure 4-10. 2006-2014 gas production for the KTF Area based on Texas Railroad Commission (TRC) oil and gas activity data (well counts are as of the beginning of February in each year).

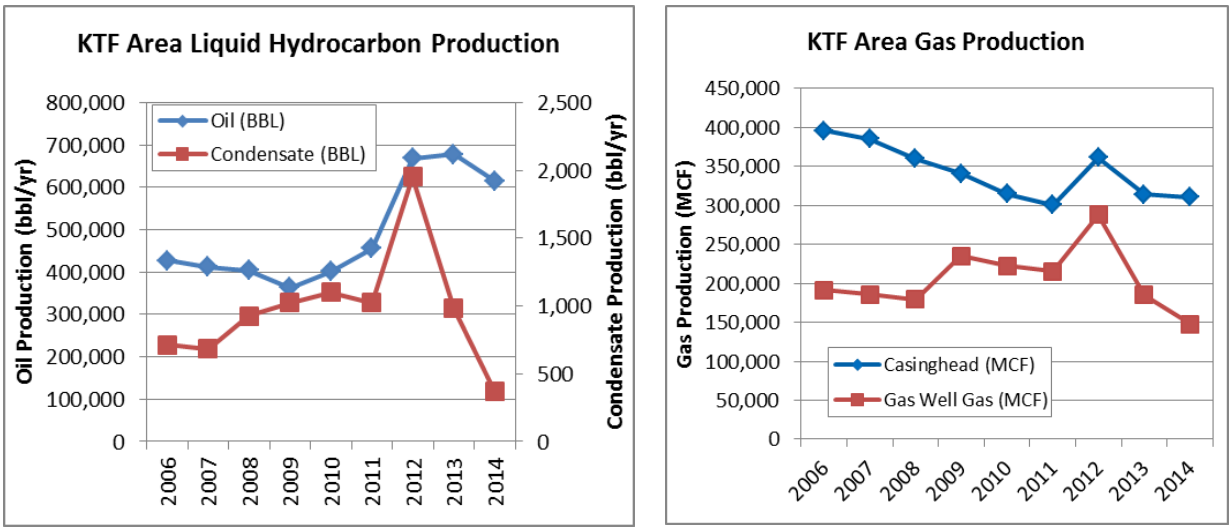

Figure 4-11. 2006-2014 liquid hydrocarbon production (left) and gas production (right) for the KTF Area based on TRC oil and gas activity data.

Figure 4-12 shows oil and gas versus non-oil and gas area source emissions of NOx and VOC by county. Oil and gas emissions contribute a vast majority of area source NOx and VOC emissions in Milam County, but only a small fraction of area source emissions in other counties. Figure 4-13 and Figure 4-14show 2012 area source emission contributions by source category in the KTF Area. Fuel combustion and oil and gas emissions account for 50% and 42% of NOx

emissions, respectively. VOC emissions have large contributions from a number of source categories; oil and gas, gasoline distribution, and consumer products account for 38%, 17%, and 16% of emissions, respectively, while the remaining area sources account for close to 30% of area source VOC emissions.

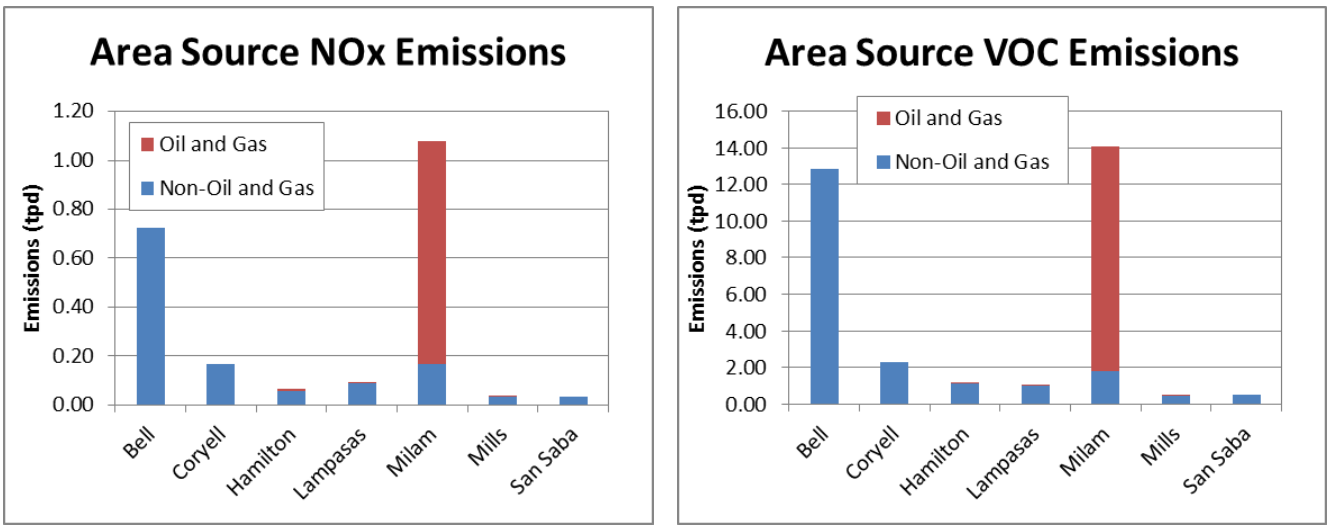

Figure 4-12. Area source NOx (left) and VOC (right) emissions by county for the KTF Area.

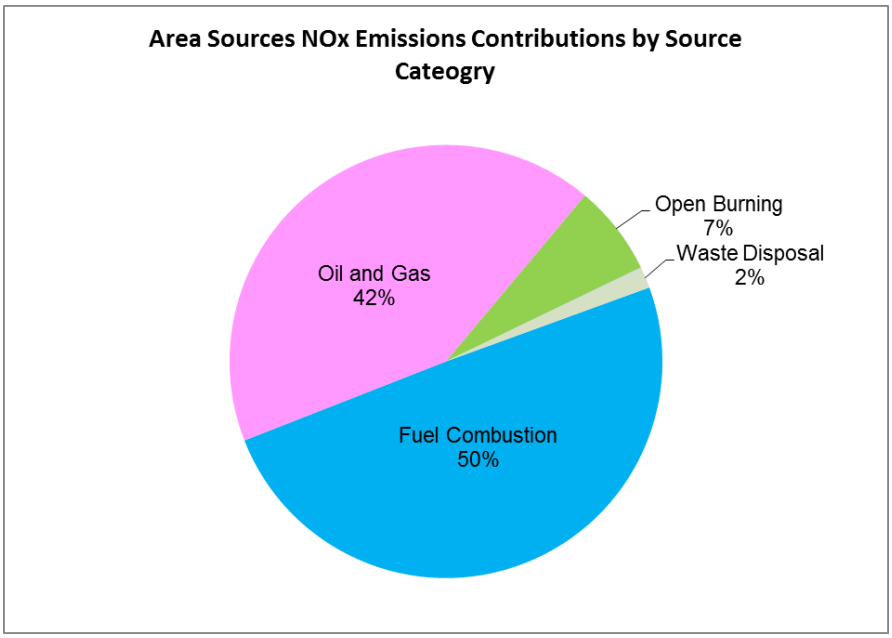

Figure 4-13. KTF Area 2012 area source NOx emissions emission by source category.

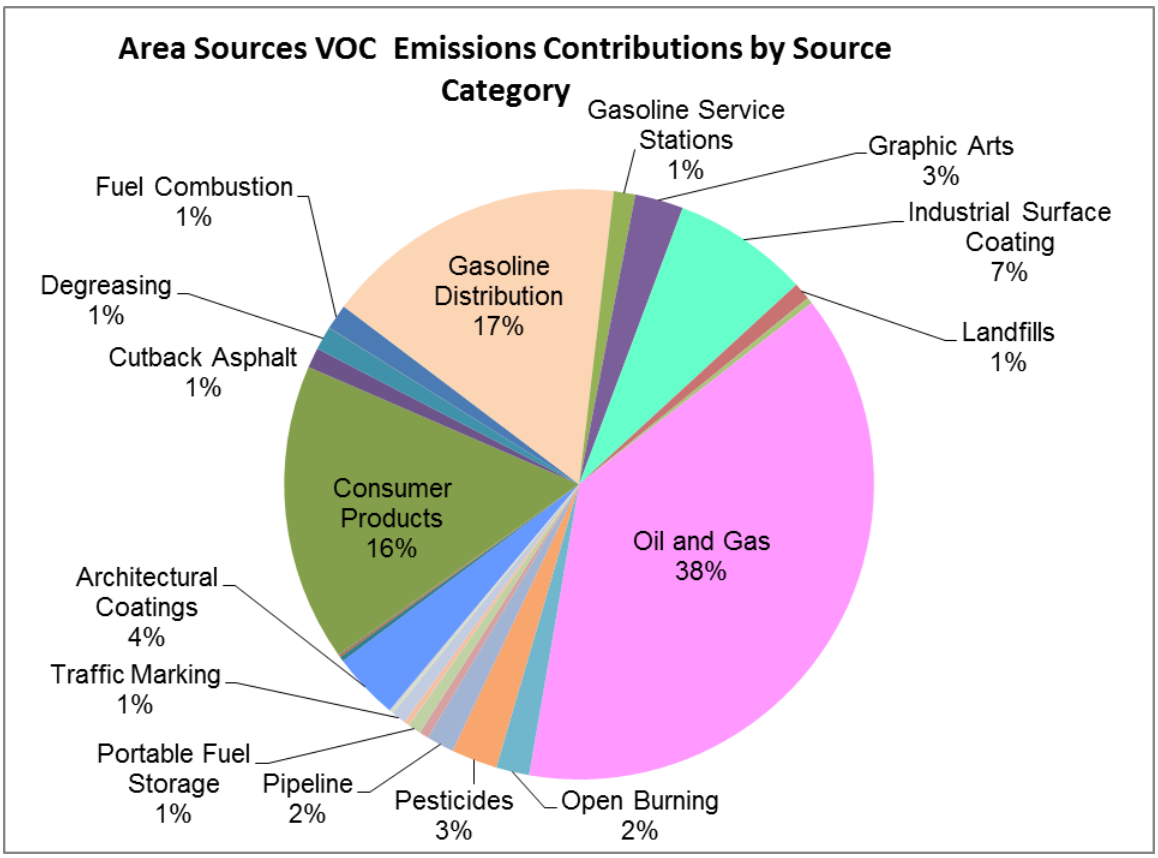

Figure 4-14. KTF Area 2012 area source VOC emissions emission by source category.

Oil and gas emission contributions to area source emissions by source category are shown in Figure 4-13 and Figure 4-14. The largest source of oil and gas NOx emissions is artificial lift engines (63%) while heaters comprise 31% and compressor engines comprise 6% of NOx emissions. The largest sources of VOC emissions are pneumatic devices (36%), well venting (27%) and crude oil tanks (22%).

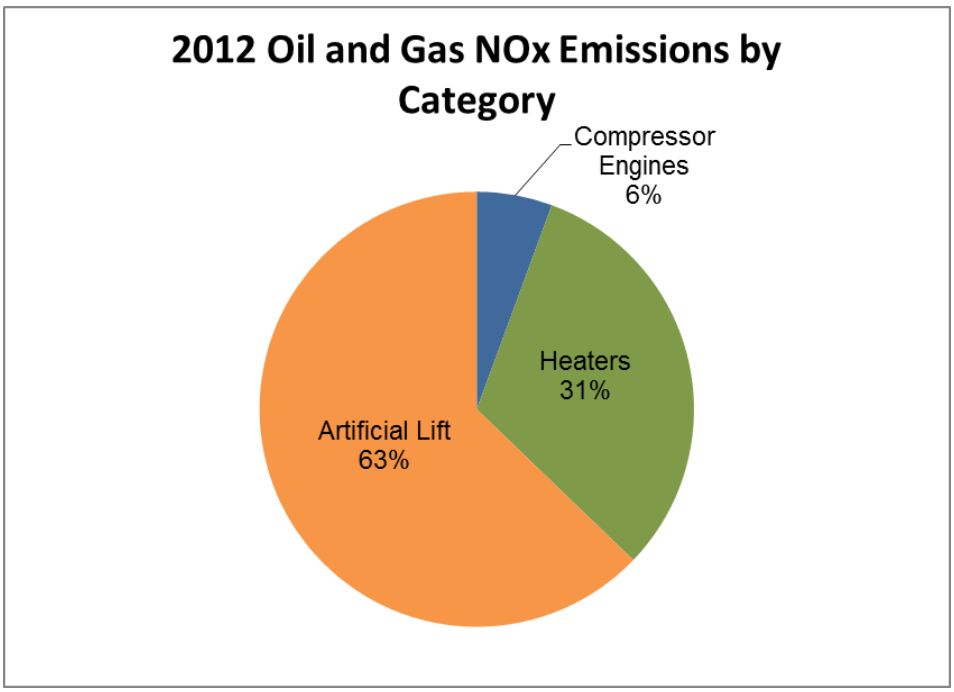

Figure 4-15. KTF Area 2012 oil and gas source NOx emissions by source category.

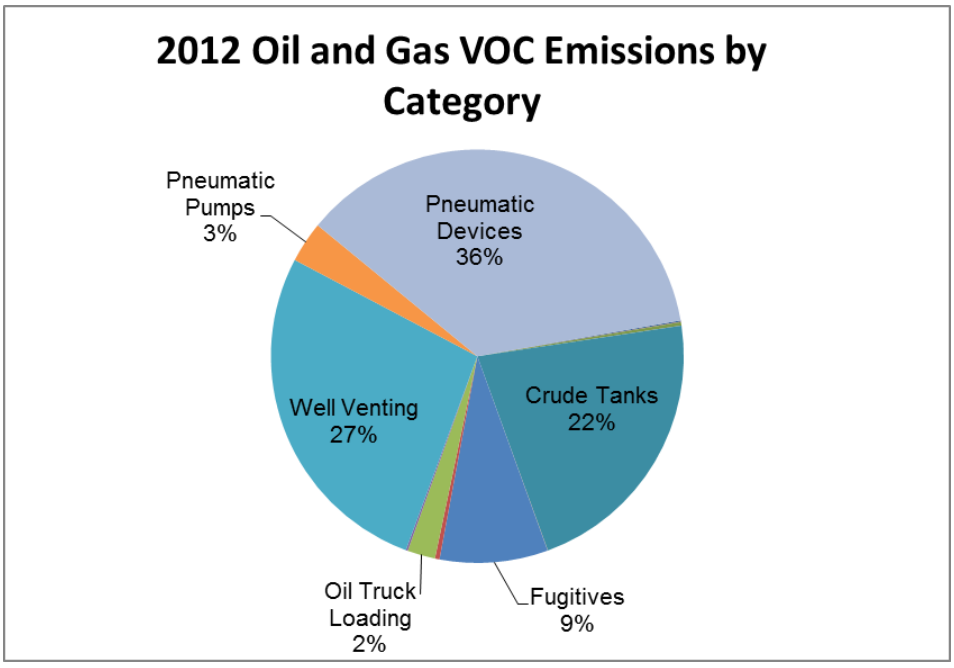

Figure 4-16. KTF Area 2012 oil and gas source VOC emissions by source category.

4.4.5 Analysis

The emissions analysis below focuses on those categories responsible for the preponderance of area source NOx and/or VOC emissions in the KTF Area for which emission updates could have significant effects on the emission inventory.

4.4.5.1 Oil and Gas Emissions

TCEQ (2014b) provides a description of the basis of the oil and gas area source emissions development. Oil and gas emission inventory estimates are primarily based on the ERG (2010a) study with updates to emission factors and equipment profiles for a number of source categories as listed below.

Condensate tank emission estimates were based on a methodology described in ERG (2012). Condensate tank emission rates are typically estimated using software such as the E&P Tank model or the HYSYS process simulator; condensate production is multiplied by condensate tank emission rates to estimate county-level emission estimates; flaring or vapor recovery may be used to control condensate tank VOC emissions. Uncontrolled VOC emission factors for the Western Gulf Region (11.0 pounds VOC per barrel of condensate) were applied in Bell County, for the Barnett Shale Region (9.65 pounds VOC per barrel of condensate) were applied in Hamilton, Lampasas, Mills, and San Saba County, and for the Eagle Ford Region (10.5 pounds VOC per barrel of condensate) were applied in Milam County. Barnett Shale emission factors were estimated based on data gathered as part of the Barnett Shale Area Special Inventory (BSASI)[19]; emission factors for other areas were estimated based on survey data provided by 15 companies across multiple target counties (no KTF Area counties were targeted in the survey) as described in ERG (2012). A control factor of 11.8%, estimated based on the BSASI, accounts for the fraction of emissions that are controlled and estimated control efficiency state-wide. The BSASI was compiled based on a compulsory request by TCEQ to Barnett Shale operators to provide specific oil and gas emissions data, including data for condensate tanks, and obtained a very high response rate (greater than 90% of all condensate production reported). Since the TCEQ 2012 emissions are based on emission factors estimated from surveys of Barnett Shale condensate tanks, they can be considered reasonably representative of the KTF Area Barnett Shale counties condensate tank emissions. While the condensate emission factors from ERG (2012) are not based on KTF Area data, since condensate production is low in the KTF Area, condensate tank emissions are not expected to be a large source of emissions, thus this source category is not recommended for update. The EPA New Source Performance Standard Subpart OOOO requires controls on tanks emitting more than six tons of VOC per year after August 23, 2011. In 2012, the effect on emissions is expected to be small as it only applies to wells drilled

[19] "Barnett Shale Area Special Inventory, Phase One", TCEQ, 2009, http://www.tceq.texas.gov/assets/public/implementation/air/ie/pseiforms/Barnett%20Shale%20Area%20Special%20Inventory.pdf, "Barnett Shale Phase Two Special Inventory Data", TCEQ, http://www.tceq.texas.gov/assets/public/implementation/air/ie/pseiforms/summarydatainfo.pdf

and/or modified in late 2011 and 2012. However, for future year emission inventories the effect of Subpart OOOO on emissions will need to be accounted for.

Heater emission estimates were developed based on equipment profiles and emission factors by region in ERG (2013). Since 99% of heater emissions in the KTF Area are from Milam County, the discussion that follows is focused on Milam County heater inputs. Milam County heater emissions were estimated based on data gathered as part of ERG (2013) for the Eagle Ford Shale formation. The Eagle Ford heater profiles used to estimate 2012 emissions assumed the presence of 0.54 heaters per well, operating 86% of the year on average, with an average size of 0.906 million BTU per hour (MMBTU/hour). This estimate is based on responses from 11 operators representing 61% of liquid hydrocarbon production in the Eagle Ford Shale area. The KTF Area liquid hydrocarbon production represents less than 3% of liquid hydrocarbon production from the Eagle Ford Shale formation; the degree to which any KTF Area operators were included in the heater data is unknown because operator names were not provided in the report.

Pneumatic devices emissions were estimated based on survey data collected as part of the BSASI study for the KTF Area Barnett Shale counties; for counties outside of the Barnett Shale, including Milam County, emissions were estimated based on a TCEQ survey for the rest of Texas. EPA New Source Performance Standard Subpart OOOO requires use of low-bleed pneumatic devices (i.e. pneumatic devices that are rated at 6 standard cubic-feet of gas per hour (scf/hr) or lower) from August 23, 2011 at new or modified wells. The 2012 pneumatic device emissions do not reflect EPA New Source Performance Standard Subpart OOOO controls. Since Subpart OOOO only applies to new or modified wells installed from August 23, 2011, the effect of Subpart OOOO is expected to be small in the 2012 emission inventory. However, future year inventories will need to consider the effect Subpart OOOO on pneumatic device emissions.

Pneumatic pump emissions were estimated based on EPA oil and gas emissions tool equipment profiles and operational characteristics. Pneumatic pump emissions are not currently based on data specific to the KTF Area and should be considered for update.

Compressor engine emissions were estimated based on BSASI data. TCEQ (2014b) described this as follows:

> *TCEQ conducted the Barnett Shale Special Inventory in 2011, obtaining data from over 8,000 sites that operated in the Barnett Shale in 2009, including information from over 1,850 compressor engines. This compressor engine data was combined with control requirements from the TCEQ Chapter 117 NOx rules to develop updated compressor engine profiles and emission factors for the DFW non-attainment counties, the Barnett Shale attainment counties, and the East Texas area.*

The KTF Area counties are not subject to TCEQ Chapter 117 NOx rules. BSASI equipment characteristics and operational profiles were used to estimate NOx emissions from compressor engines in the KTF Area.

Table 4-6 summarizes the methodology used to compile oil and gas emissions for each oil and gas source category as presented in ERG (2010a) and based on communication with TCEQ staff (TCEQ, 2014b). Source categories not based on local data are recommended for update except for gas well related source categories which are not recommended for update due to their small associated emissions in the KTF Area.

Table 4-6. Oil and gas emissions methods summary by source category.

Source Category	Brief description of how unit-level emissions were estimated*	Recommended for Update?
Artificial Lift (Pumpjack) Engines	Engines were assumed to operate at any oil well greater than one year old. State-wide assumptions were implemented as follows: 70% of pumpjack engines are electric, uncontrolled emissions factors were applied (assumed that no engines meet NSPS standards), horsepower, load factor, and annual usage were estimated for a typical engine.	Yes, should be updated based on local data.
Compressor Engines	As described above, KTF Area compressor engine emissions are based on Barnett Shale data collected as part of the BSASI.	No
Dehydrators	Emissions per unit of gas production were estimated based on central facility dehydrator GLYCalc reports and controls. ERG (2010a) indicates that these estimates may be biased low because application of dehydrator controls at well sites may be different than at central facilities.	No
Fugitives Components	The number of devices per well were taken from Bar-Ilan et al. (2008) for the Fort Worth Basin. AP-42 emission rates per device were applied. The extent to which data was collected in the KTF Area is unknown.	Yes, KTF Area fugitive component activity should be updated.
Crude Oil Storage Tanks	Emissions were estimated based on emission factors in TERC (2009). TERC (2009) emission factors were based on measurements at 11 oil tanks, none of which were located in the KTF Area.	Yes, KTF Area specific emission factors should be updated.
Condensate Storage Tanks	Condensate tank emissions were estimated based on emission factor and control information as described above.	No
Heaters	Heater emissions were estimated based on emission factor and equipment configuration estimates in ERG (2013) and TRC estimates of well count.	Yes, the extent to which local Milam County data was used in ERG (2013) should be explored.
Tank Truck/Railcar Loading of Crude Oil and Condensate	Emission rates per barrel loaded were estimated using AP-42 methodology. Assumed that all crude oil and condensate production in each county is loaded once.	No
Well Venting (blowdowns)	Average blowdown frequency per well and vented volume was taken from Bar-Ilan et al. (2008); the extent to which data was collected in the KTF Area is unknown.	Yes, KTF Area blowdown activity should be updated.
Well Completions	Average completion vented volume per well and prevalence of flaring and green completion control were taken from Bar-Ilan et al. (2008) which did not contain information on green completions. EPA Subpart OOOO regulation requires VOC	Yes, well completion emission estimates do not include the effects of EPA Subpart OOOO regulations.

Source Category	Brief description of how unit-level emissions were estimated*	Recommended for Update?
	emissions from completions at hydraulically fractured wells drilled after August 23, 2011 to be controlled by flare; for wells drilled after January 1, 2015, control by green completion techniques is required.	
Pneumatic Pumps	As described above, pneumatic pump emissions were estimated based on EPA oil and gas emissions tool equipment profiles and operational characteristics. Pneumatic pump emissions are not currently based on data specific to the KTF Area, but usage at oil wells is not expected.	No
Pneumatic Devices	As described above, pneumatic devices emissions were estimated based on survey data collected as part of the BSASI study and a state-wide TCEQ data collection effort.	No
Produced Water	Average emission factors from produced water were estimated from ENVIRON (2010).	No

* Oil and gas activity (e.g. number of wells, gas production, oil production) was taken from Texas Railroad Commission (TRC) databases and applied to unit-level estimates to develop emission inventory estimates. For example, heater emissions were estimated by multiplying the unit-level estimate of average heater emissions per well by the number of oil and gas wells in a given county.

As described in Table 4-6, there are source categories of emissions from oil wells (which are the dominant well type in the KTF Area) which are not based on KTF Area for which emission estimates rely on data that is outdated and/or not specific to Milam County. Artificial lift engines, the largest source of oil and gas NOx emissions in the KTF Area, and a number of other categories rely on state-level or data not specific to the KTF Area.

4.4.5.2 Fuel Combustion Emissions

Area source fuel combustion estimates are based on state-level fuel consumption activity data which typically includes consumption from point and area sources and is obtained from the Energy Information Administration (EIA). Area source-specific fuel consumption is estimated by allocating state-level consumption estimates to the county-level and reconciling county-level fuel consumption estimates with point source fuel consumption. Because the reconciliation step requires compiling both fuel consumption estimates and reconciling those fuel consumption estimates against point source fuel consumption, a separate study would need to be performed to confirm the accuracy of the TCEQ emission inventory estimates for area source fuel combustion. Given that these emissions are a relatively small component of the KTF Area inventory (<3% of total anthropogenic NOx emissions), such a study is not recommended.

4.4.5.3 Fort Hood Area Sources

Population-based area source emission estimates (e.g. consumer products) include emissions from persons living temporarily or permanently on the Fort Hood Base based on US Census estimates of Fort Hood population (TCEQ, 2015b). The U.S. Census lists Fort Hood as a census

designated place with a 2010 human population of 29,589[20]. The extent to which commercial or industrial area sources such as solvent usage or surface coating operations are either missing from or included in the area source emission inventory is unknown at this time (TCEQ, 2015b).

4.4.5.4 Gasoline Distribution Emissions

Gasoline distribution emissions account for about 11% of total anthropogenic VOC emissions. Gasoline distribution emissions are associated with transport and delivery of gasoline and include the following types of emissions: Stage I (transfer from tanker truck to service station tanks), Stage II (vehicle refueling), storage tank breathing and evaporative emissions associated with truck transport. A study of gasoline distribution emissions by ERG (ERG, 2008a) commissioned by TCEQ is the source of gasoline distribution emissions in the 2012 TCEQ emission inventory.

The ERG (2008a) study surveyed 3,000 service stations in Texas, 46 of which were in KTF Area counties, to obtain station specific data for gasoline tank throughput. Based on information provided by survey respondents (23.4% response rate) about tank throughput and tank volume data available from TCEQ underground storage tank records, a model was developed that estimated annual throughput of a given gasoline storage tank based on the storage tank's capacity by grade of fuel.

Emission rates in ERG (2008a) for each process were estimated according to standard methodology for each source as described below. Uncontrolled Stage I and Stage II emission rates were assumed for KTF Area.

- Stage II (refueling): Emission rates estimated based on MOBILE6 model. It is noted that MOBILE6 is no longer the preferred model for estimating Stage II emission rates; the current preferred model to estimate Stage II emission rates is the MOVES model.
- Stage I (transfer from tanker truck to service station tanks): AP-42, section 5.2 emission rates were applied for submerged filling.
- Storage tank breathing: AP-42, section 5.2 emission rates.
- Truck transport: AP-42, section 5.2 emission rates.

Ramboll Environ compared total estimated throughput for Texas in ERG (2008a) with EIA data and found significant differences in gasoline throughput estimates (see Table 4-7).

Table 4-7. Texas state-wide annual gasoline consumption.

Year	Source	Annual Gasoline Consumption (billion gallons)
CY2007	ERG (2008a)	17.8
CY2007	Energy	12.2

[20] http://quickfacts.census.gov/qfd/states/48/4826736.html

Year	Source	Annual Gasoline Consumption (billion gallons)
CY2012	Information Administration[1]	12.7

[1] Texas State Profile and Energy Estimates, http://www.eia.gov/state/?sid=tx

Additional data could be used to evaluate whether annual gasoline throughput estimates in the KTF Area are in reasonable agreement with records of annual gasoline consumption which should be available from a state or local agency based on sales tax records receipts. However, given the magnitude of emissions from gasoline distribution (5.3 tpd in 2012), even a decrease of 50% in these emissions would only represent a decrease of 5% in anthropogenic VOC emissions. Update of this source category is a low priority as this update will only result in changes to VOC emissions.

4.5 Point Source Emissions Review

Point sources are large stationary emissions sources that exceed a specified emissions threshold. Point source emissions are frequently but not always released through an exhaust stack. In non-attainment areas, the TCEQ defines a point source to be any industrial, commercial or institutional source that emits actual levels of criteria pollutants at or above the following amounts: 10 tons per year (tpy) of VOC; 25 tpy of NOx; or 100 tpy of any of the other criteria pollutants including CO, SO_2, PM_{10}, or lead. In attainment areas of the state, such as the KTF Area, any facility that emits a minimum of 100 tpy of any criteria pollutant must submit a point source emissions inventory to the TCEQ. Each point source has a well-defined location (latitude and longitude) as well as ancillary information known as stack parameters that indicate the height at which emissions are released, the diameter of the emitting stack, and other factors. As with all other TCEQ ozone modeling emission inventories, the 2012 point source inventory contains air emissions of the following ozone precursors: NOx, VOC and CO.

4.5.1 2012 Point Source Emissions

The TCEQ developed state-wide 2012 emissions from data from the TCEQ's State of Texas Air Reporting System (STARS) and the EPA's Acid Rain Program. While there is currently no publicly available documentation specific to this emission inventory, documentation is expected to be released by TCEQ in 2015.

The STARS database is administered by the TCEQ. Each year the TCEQ sends questionnaires to all facilities that meet reporting requirements of 30 Texas Administrative Code (TAC) §101.10. The TCEQ collects point source emissions data as well as industrial process operating data. For all sources except electric generating units (EGUs), the TCEQ uses this data to compile ozone season day (OSD) emissions. The OSD emissions represent average daily emissions during the summer when ambient ozone in Texas is highest.

The EPA requires all existing utility units serving generators with an output capacity of greater than 25 megawatts (MW) and all new utility units to continuously measure and record their emissions of SO_2, NOx and CO_2 as well as other quantities such as heat input of fuels. This is

accomplished through in-stack monitoring using a Continuous Emissions Monitor (CEM). All sources must submit hourly emissions data to the EPA's Clean Air Markets Division (CAMD) Acid Rain Program Database (ARPDB) on a quarterly basis.

Typically, hourly EGU emissions are used in ozone modeling to provide the most accurate possible simulation of emissions as well as transport and fate of EGU emissions, however, TCEQ OSD average emissions were generated for EGUs from the hourly data for the emissions analysis presented here.

4.5.1.1 Emission Summary

The TCEQ 2012 point source emission inventory is summarized below in several different ways to establish (1) the geographical distribution of point source emissions, (2) the relative importance of point source emissions by industry and (3) the relative importance of emissions sources by the mass of pollutants emitted. Appendix B includes a table of TCEQ estimates of point source emissions by facility.

In the KTF Area, point sources produce a smaller amount of NOx emissions than on-road vehicles, off-road equipment, and biogenics sources, and accounted for 15% of the total KTF Area NOx emissions in 2012 (Figure 4-1). Point source emissions account for very minor contributions to total VOC emissions, representing less than 1% of the total VOC emissions in the KTF Area. Figure 4-17 shows the location of the KTF Area point sources in the 2012 TCEQ emission inventory. Source locations for the ten KTF Area point source facilities were taken directly from modeling files. The size of the facility location circle represents the magnitude of facility-level NOx emissions.

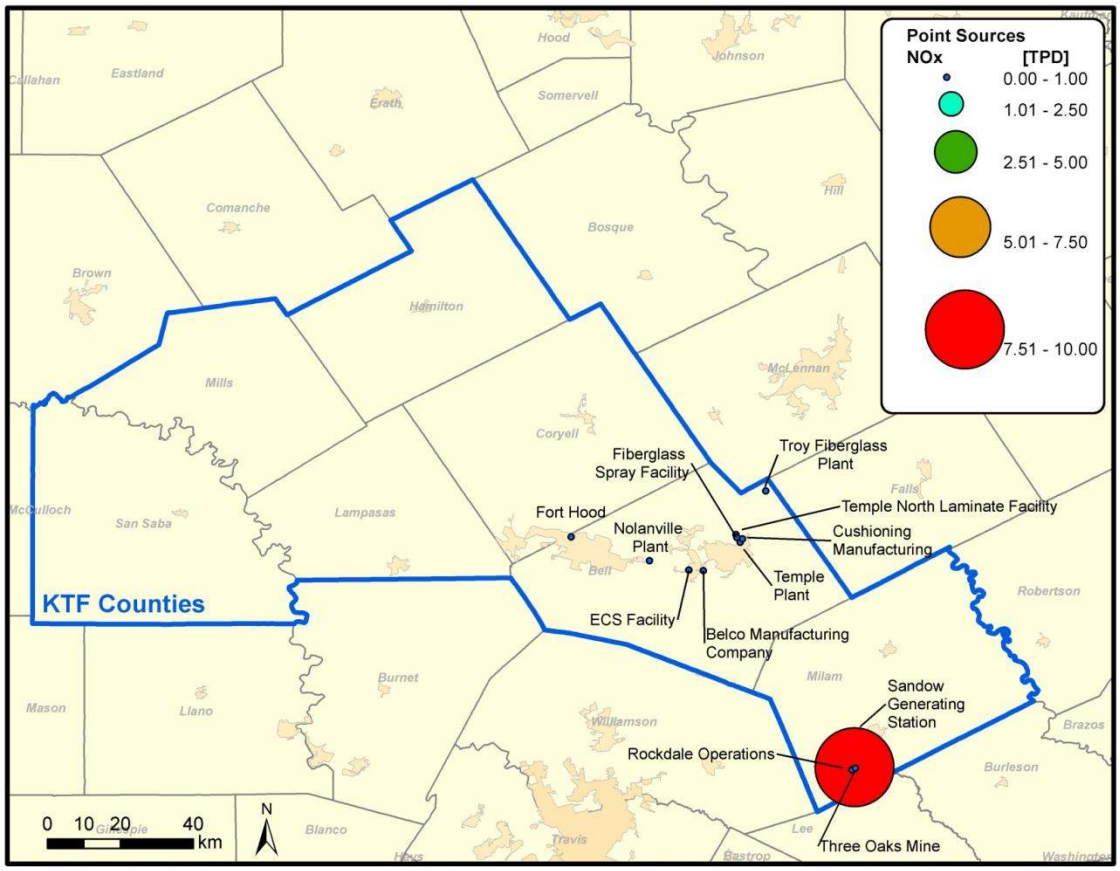

Figure 4-17. Map showing location of KTF Area point sources in the TCEQ 2012 NOx emission inventory.

Table 4-8 shows the KTF Area point sources emissions by facility in the 2012 emission inventory. The Sandow Generating Station is by far the largest NOx emissions source accounting for 97% of point source NOx emissions; there are six other NOx emitting facilities which account for the remaining 3% of NOx emissions and five point sources have no NOx emissions whatsoever. The Temple Plant is the largest VOC source, accounting for 31% of the point source VOC emissions. The Troy Fiberglass Plant, ECS Facility, Sandow Generating Station, and Belco Manufacturing Company facilities each have VOC emissions greater than 0.2 tons/day and account for 13%, 13%, 11%, and 9% of point source VOC emissions, respectively.

Table 4-8. Top-emitting NOx and VOC point sources in KTF Counties.

Facility	2012 NOx			Facility	2012 VOC	
	tons/ day	Percent of KTF Area point emissions			tons/ day	Percent of KTF Area point emissions
Sandow Generating Station	8.901	97%		Temple Plant	0.69	31%
Temple North Laminate Facility	0.164	2%		Troy Fiberglass Plant	0.28	13%
Fort Hood	0.079	1%		ECS Facility	0.28	13%
Rockdale Operations	0.028	<0.5%		Sandow Generating Station	0.24	11%
Nolanville Plant	0.017	<0.5%		Belco Manufacturing Company	0.20	9%
Cushioning Manufacturing	0.008	<0.5%		Cushioning Manufacturing	0.17	7%
Temple Plant	0.006	<0.5%		Temple North Laminate Facility	0.16	7%
Troy Fiberglass Plant	-	0%		Fort Hood	0.15	7%
ECS Facility	-	0%		Nolanville Plant	0.03	1%
Belco Manufacturing Company	-	0%		Fiberglass Spray Facility	0.03	1%
Fiberglass Spray Facility	-	0%		Rockdale Operations	0.01	<0.5%

Next, we examine the breakdown of point source emissions by type of emitting facility. Facilities are categorized by type by their Standard Industrial Classification (SIC) code which is a four-digit numerical code assigned by the U.S. Securities and Exchange Commission that is unique to each type of industry. Table 4-9 shows emissions by SIC code. The Electric Services sector, which encompasses EGUs and electricity transmission and distribution, is the largest source of point source NOx emissions in the KTF Area, accounting for 97% of NOx emissions; the Sandow Generating Station is the only Electric Services sector facility in the KTF Area, and, thus, accounts for all of the Electric Services sector emissions in the KTF Area. The Plastic Products sector accounts for 2% of point source NOx emissions. The largest contributor to point source VOC emissions is the Plastics Foam Products sector (38%); the Industrial Buildings and Warehouses and the Nonclassifiable Establishments sectors are the next largest VOC emitters and each account for 13% of point source VOC emissions.

Table 4-9. KTF Counties point source emissions by industrial sector.

SIC	SIC Description	Emissions (tons/day)		Percent of Emissions	
		NOx	VOC	NOx	VOC
4911	Electric Services	8.9	0.2	97%	11%
3089	Plastics Products	0.2	0.2	2%	7%
9711	National Security	<0.1	0.1	1%	7%
3334	Primary Aluminum	<0.1	<0.1	0%	0%
3296	Mineral Wool	<0.1	<0.1	0%	1%
3086	Plastics Foam Products	<0.1	0.9	0%	38%
9999	Nonclassifiable Establishments	<0.1	0.3	0%	13%
1541	Industrial Buildings And Warehouses	<0.1	0.3	0%	13%
5075	Warm Air Heating & Air-Conditioning	<0.1	<0.1	0%	1%

SIC	SIC Description	Emissions (tons/day)		Percent of Emissions	
		NOx	VOC	NOx	VOC
2221	Broadwoven Fabric Mills, Manmade	<0.1	0.2	0%	9%
Totals		**9.2**	**2.2**	**100%**	**100%**

4.5.1.2 Fort Hood Point Sources

According to TCEQ's 2014 Emission Inventory Guidelines (TCEQ, 2015c), point sources must be reported to TCEQ in attainment areas such as the KTF Area when a facility's actual or potential emissions exceed 100 tons per year for any criteria pollutant, 10 tons per year for any individual hazardous air pollutant, or 25 tons per year for aggregated HAP emissions. Fort Hood emissions reported to TCEQ for 2012 did not exceed any reporting criteria in 2012. It is possible that even though Fort Hood does not meet TCEQ's reporting criteria, it purposefully reports under another authority. Since the facility is not required to report under TCEQ guidelines, it is unclear which sources/units were reported or not reported in the 2012 emission inventory (TCEQ, 2015d).

4.5.1.3 Sandow Generating Station

Luminant operates the Sandow Generating Station, which is a coal-fired power plant with a generation capacity of 1,137 MW[21]. Lignite coal for the power plant is obtained from the Three Oaks Mine in Lee County Texas, south of the KTF Area. Sandow Generating Station is the single largest NOx emission source in the KTF Area, comprising 14% of area-wide NOx emissions. There are two boiler units at the facility, Unit 4 and Unit 5, both of which are baseload units. Unit 4 was built in 1981; its 2012 OSD emissions were 4.6 tpd. Unit 5 was built in 2009; its 2012 OSD emissions were 4.2 tpd. Control equipment on Unit 4 includes selective catalytic reduction and a low NOx fluidized-bed boiler while Unit 5 includes selective non-catalytic reduction and a low NOx fluidized-bed boiler[21]. Boiler units 1, 2, and 3 are no longer operational; these boilers were permanently retired in 2006 per the Alcoa, Inc. Clean Air Act Settlement[22].

4.5.1.4 Panda Temple Power Project

The Panda Temple Power Project is a new natural gas fueled combined-cycle power plant located in Temple (Figure 4-18). The facility is being built in two phases, with each phase consisting of two combustion turbines and one steam turbine with total capacity of 758 MW, so that the entire facility will have capacity of 1516 MW. The TCEQ approved the permit for the

[21] http://luminant.com/plants/pdf/Sandow_Facts.pdf
[22] http://www2.epa.gov/enforcement/alcoa-inc-clean-air-act-settlement

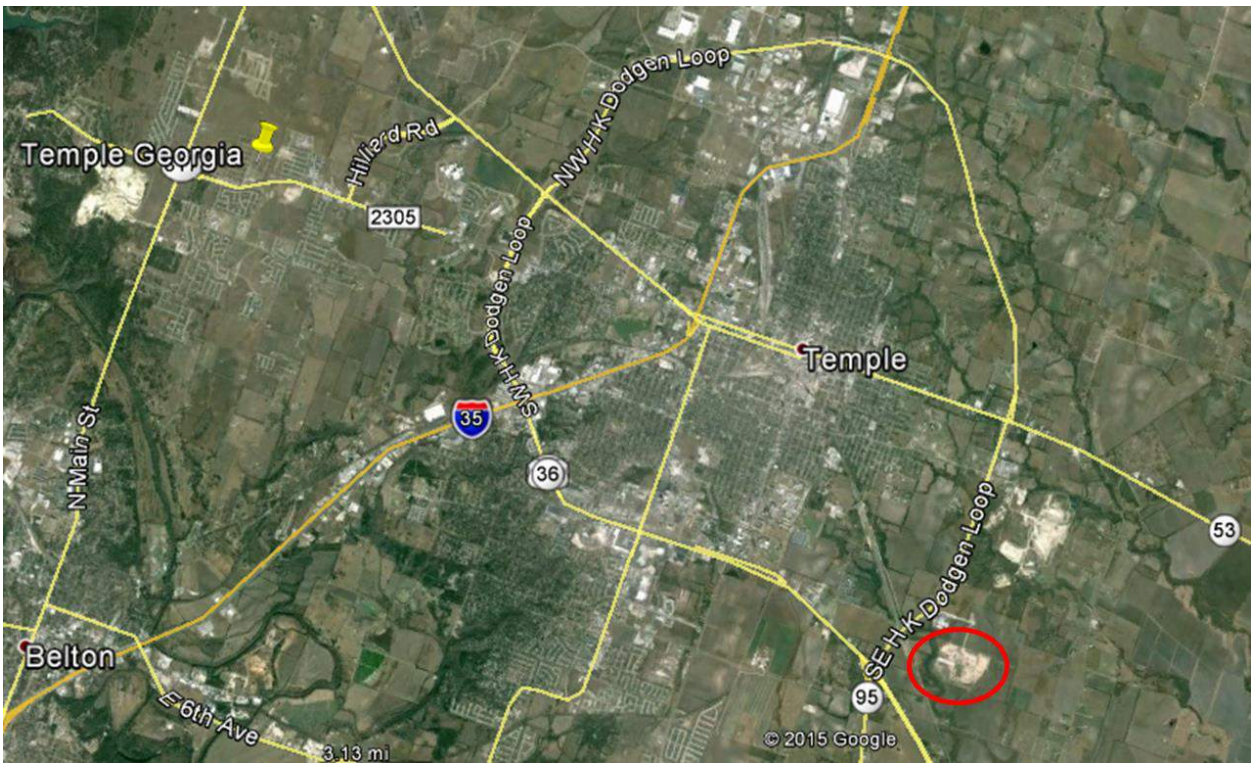

Figure 4-18. Panda Temple Power Project location. Power plant location is circled in red. Location of the Temple Georgia ozone monitor is shown in yellow.

Panda Temple Power Project in October, 2008. Construction on the first phase of the project, the Panda Temple I Generating Station, began in 2012. Panda Temple I commenced operations in July 2014. Construction on the second phase of the Project, Panda Temple II Generating Station, began in April 2013 and Phase II is projected to be operational by the end of 2015.

Panda Temple I and II are identical in equipment and configuration and are designed to be used as both baseload and peaking units[23]. As peaking units, they will have higher power output during hot weather, when air conditioner use is high[24]. This means the facility will be running at high capacity on days which are most likely to have high ozone levels. Because the units generate power through combustion of natural gas, they will have NOx emissions. Evaluation of the TCEQ's 2012 emission inventory indicates that ozone formation in the KTF Area is NOx-limited, and so an additional source of NOx in close proximity to an ozone monitoring site (~8 miles from Temple Georgia) may have impacts on monitored ozone.

[23] http://www.bizjournals.com/dallas/news/2013/11/21/panda-power-fired-up-about-three-new.html
[24] http://www.pandafunds.com/invest/temple/

The Panda Temple units have NOx emissions controls consisting of dry low NOx burners and selective catalytic reduction (SCR). These controls are consistent with current practice for new combined-cycle units in Texas. The facilities are slated to come up to 60% of baseload in 20 minutes, and arrive at full power in an hour. This reduces the amount of time when the unit is operating in startup mode and the temperature of the exhaust is not yet high enough for the SCR NOx emissions control unit to function at full efficiency.[25]

The Panda Temple facility came online after 2012 and is not present in the current TCEQ ozone modeling emission inventory. Therefore, its ozone impacts will not be evaluated under Task 5 of this project. We recommend that an analysis of emissions from the facility be performed in the future. If NOx emissions appear significant, then the potential ozone impacts of this facility should be modeled in order to understand its influence on ozone at the Temple Georgia and Killeen ozone monitors.

4.6 Recommendations

Below is a list of recommendations aimed at improving our understanding of ozone precursor emissions in the KTF Area. These recommendations are listed below in order of importance as determined by Environ; NOx emissions updates are a higher priority than VOC emission updates because ozone formation in the KTF Area is expected to be NOx-limited.

1. Emissions from Fort Hood military post off-road equipment, area sources, on-road vehicles, and point sources are uncertain. Specific sources of uncertainty that should be addressed are off-road emissions from sources such as military tanks, armored vehicles, and helicopters; industrial area sources (e.g. solvent usage, degreasing); on-base on-road vehicle emissions; and thresholds that were used to determine which emission sources were reported in the Fort Hood point source emission inventory. (*High priority*)

2. An analysis of emissions from the new Panda Temple I and II Generating Stations should be performed. If NOx emissions appear significant, then the potential ozone impacts of this facility should be modeled in order to understand its influence on ozone at the Temple Georgia and Killeen ozone monitors. (*High priority*)

3. For the following oil and gas source categories: artificial lift (pumpjack) engines, fugitives components, crude oil storage tanks, heaters, well venting (blowdowns), and well completions, emission calculation assumptions are generally based on potentially outdated studies or not based on data that encompasses recent drilling and production activity in the KTF Area and should be updated. (*Medium priority for artificial lift engines, low priority for all other sources*)

[25] http://www.power-eng.com/articles/2014/09/texas-panda-temple-combined-cycle-plant-up-and-running.html

4. Gasoline distribution volume estimates should be obtained from the Texas Comptroller's office to verify that reasonable gasoline throughput volumes are used in the ERG (2008a) study. Obtaining annual gasoline throughput estimates from the Texas Comptroller's office and comparing those throughput estimates to throughput estimates in ERG (2008a) is likely to require minimal effort. (*Low priority*)

5.0 AMBIENT DATA ANALYSIS

In this Section, we analyze ambient ozone and weather data gathered in the KTF Area from 2009 to 2014 to form a general picture of the nature of ozone air quality in the KTF region. The ambient data analysis includes an investigation of the possible relationships between weather conditions and high ozone, and identifies distinct meteorological phenomena associated with high ozone. In addition, analyses to link specific wind directions and long-range atmospheric transport patterns to high ozone are performed. The draft EPA modeling guidance (EPA, 2014b) details these items and other ambient data analyses that may help inform a conceptual model.

Ambient ozone and meteorological data from the Killeen Skylark Field (CAMS 1047), and Temple Georgia (CAMS 1045) and Temple (CAMS 651) monitoring sites were analyzed. The Temple monitor was deactivated in November 2006 but it recorded data throughout the 2006 ozone season and is the only monitor in operation in the region at that time. It provides limited but nonetheless useful historical data for the region, since it provides a snapshot of ozone nearly a decade ago. When the Temple 2006 annual 4th highest daily maximum 8-hour average ozone (H4MDA8) concentration is viewed together with more recent H4MDA8 concentrations for the KTF region, and in relation to decadal length H4MDA8 concentrations that are available for other surrounding areas, the data suggests that the KTF region is likely experiencing improved ozone air quality in recent years compared to 2006 (Parker et al., 2015).

Because the Killeen monitor has the longest data record, data from Killeen forms the basis for most of the analyses presented in this Section. Analysis of the data from the recently operational Temple Georgia monitor is also presented and as more years of data become available, a more robust analysis of conditions at this site will become possible.

Section 5.1 presents an analysis of high ozone days, where high ozone days are defined by different MDA8 ozone threshold concentrations (i.e. MDA8 greater than 60, 65, 70 and 75 ppb), and the analysis is performed for different temporal periods (i.e. by-year, by-month, by-day-of-the-week, and by-time-of-day). Section 5.2 presents analyses that determine which wind directions are associated with high ozone days. Section 5.3 reports daily ozone time series plots for days with MDA8 > 70 ppb to investigate the time of day of peak ozone concentrations. Section 5.4 presents results from the back-trajectory analysis which is performed to assess potential source regions that may transport ozone precursor emissions into the KTF Area, via long-range transport. Section 5.5 is an analysis focused on determining the meteorological conditions associated with high ozone days. Section 5.6 presents a summary of the analysis of individual high ozone days, where for this analysis a high ozone day was defined to have MDA8 ≥ 75 ppb. Recommendations are made in Section 5.7.

5.1 Frequency Analysis of High Ozone Days: MDA8 Ozone > 60, 65, 70, 75 ppb

As discussed in Section 2, the current ozone NAAQS was set by the EPA in 2008 at 75 ppb; monitors with ozone design values exceeding 75 ppb are in violation of the NAAQS. However, in 2014, EPA proposed lowering the ozone NAAQS to a value between 65 and 70 ppb, and is taking comments on lowering it to as low as 60 ppb. Since the future level of the NAAQS is

uncertain, the following analyses have been structured to provide results that will be useful for a range of potential values of the NAAQS. As such, the frequency analysis is provided for the number of days with MDA8 ozone > 60, 65, 70, and 75 ppb. Certain days may be referred to as "high ozone days" throughout this section, this term should be interpreted as a day with MDA8 exceeding a threshold, and the particular threshold should be clear from the context.

5.1.1 By Year: Annual Trends

The annual trends in high ozone days at Killeen are presented in Figure 5-1. At all four MDA8 threshold levels, 2011 and 2012 experienced more high ozone days than the other years during 2009-2014. Note that 2009 monitoring started on June 11, therefore some high ozone days may have occurred prior to June 11 in 2009 which would not be included in the plot. 2011 had more days > 60 ppb > 65 ppb and > 70 ppb than 2012, but 2012 had more days exceeding the very highest threshold of 75 ppb.

It is useful to compare the frequency of high ozone days per year with the annual four highest MDA8 ozone concentrations, because, although these two metrics both report annual trends, their focus is quite different. The frequency analysis (Figure 5-1) provides information that may better describe an entire ozone season (particularly at the lower threshold levels). For example, from Figure 5-1 it is apparent that there were 52 days in 2011 with MDA8 > 60 ppb, which far exceeds the number of days exceeding that threshold for the other years, so high ozone concentrations (i.e. above the MDA8> 60 ppb level) were most frequently experienced in 2011. The annual four highest MDA8 ozone concentrations are presented in Figure 5-3. This metric is restricted to a much smaller set of days, (four throughout the year) and focuses on the severity of high ozone concentrations in a given year with less regard for how prolonged an episode of high ozone may be or whether there are multiple high ozone episodes in a given year. Note that the 4^{th} highest MDA8 concentration in a given year is the most important metric from a regulatory standpoint since the design value is calculated from that metric. Figure 5-3 shows that 2012 was the year that experienced the four highest MDA8 ozone concentrations from the 2009-2014 time period, followed by 2011. Note that Figure 5-1 also shows that at the MDA8 > 75 ppb threshold level, 2012 experienced more high ozone days than 2011.

In summary, both 2011 and 2012 were years that experienced high ozone more frequently than the other years. 2011 experienced days with MDA8 ozone concentrations > 60, 65, and 70 ppb more frequently than 2012, but the highest MDA8 ozone concentrations (> 75 ppb) were experienced more frequently in 2012. In addition, both 2013 and 2014 experienced relatively few high ozone days (compared to 2011/2012) and the measured four highest MDA8 ozone concentrations in 2013 and 2014 were also much lower than 2011 and 2012 by a range of 3 to 13 ppb.

Note that typically 10 years of data are required to observe annual ozone trends that may be due to changes in ozone precursor emissions. Ozone concentrations depend on meteorological factors as well as ozone precursor emissions, and with a limited data record inter-annual variations in ozone may be more reflective of meteorological variation than ozone precursor emissions changes. Meteorological influences are examined in Section 5.5.

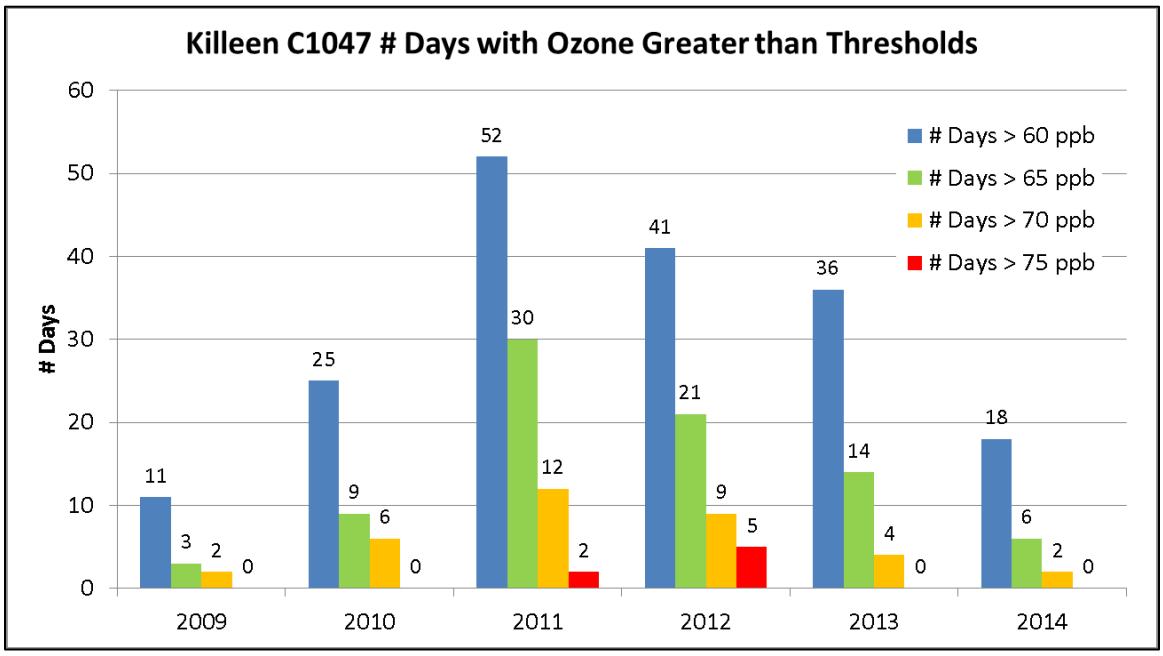

Figure 5-1. Number of days per year with ozone concentration greater than threshold levels at the Killeen monitor.

Examination of annual ozone trends at Temple is hindered by limited data; however some observations can be made. Note that data for Temple CAMS 651 (active in 2005-6) and Temple Georgia CAMS 1045 (active in 2014) are from different monitors as listed in Table 3-1 and shown in Figure 3-1, but they were both located in the same general area. The most striking observation is the large decrease in the number of high ozone days at all threshold levels between 2006 and 2014. In addition, as the MDA8 threshold increases from 60 to 75 ppb, the observed reduction in the number of days increases in a relative sense. In particular, there was about a 3-fold reduction in the number of days with MDA8 > 60 ppb, a 6-fold reduction in the number of days with MDA8 > 65 ppb and a 12-fold reduction in the number of days with MDA8 > 70 ppb. In addition there were 0 days with MDA8 > 75 ppb measured at Temple in 2014. Therefore, the greatest decline in number of high ozone days from 2006 to 2014 occurred at the higher threshold levels.

A comparison of the 2014 high ozone days at Killeen and Temple Georgia shows that the number of high ozone days at both monitors is fairly similar (Temple/Killeen: 14/18, 4/6, 1/2, 0/0) for MDA8 > 60, 65, 70, and 75 ppb, respectively. As more years of data become available, it will be possible to determine if the similarity in the number of high ozone days at these two monitors continues, and it may be possible to assess whether these two monitors are influenced by similar or different emissions sources.

Finally, Figure 5-3 shows that in 2014, the values of the four highest MDA8 ozone concentrations at Killeen and Temple Georgia are comparable. In particular, the Temple

Georgia 2014 highest annual MDA8 ozone concentration is identical to the Killeen value at 74 ppb, and the Temple Georgia 2014 4th highest MDA8 ozone concentration is two ppb lower than the Killeen value. Thus, the frequency of high ozone days, and the magnitude of high ozone concentrations were similar for Killeen and Temple Georgia in 2014.

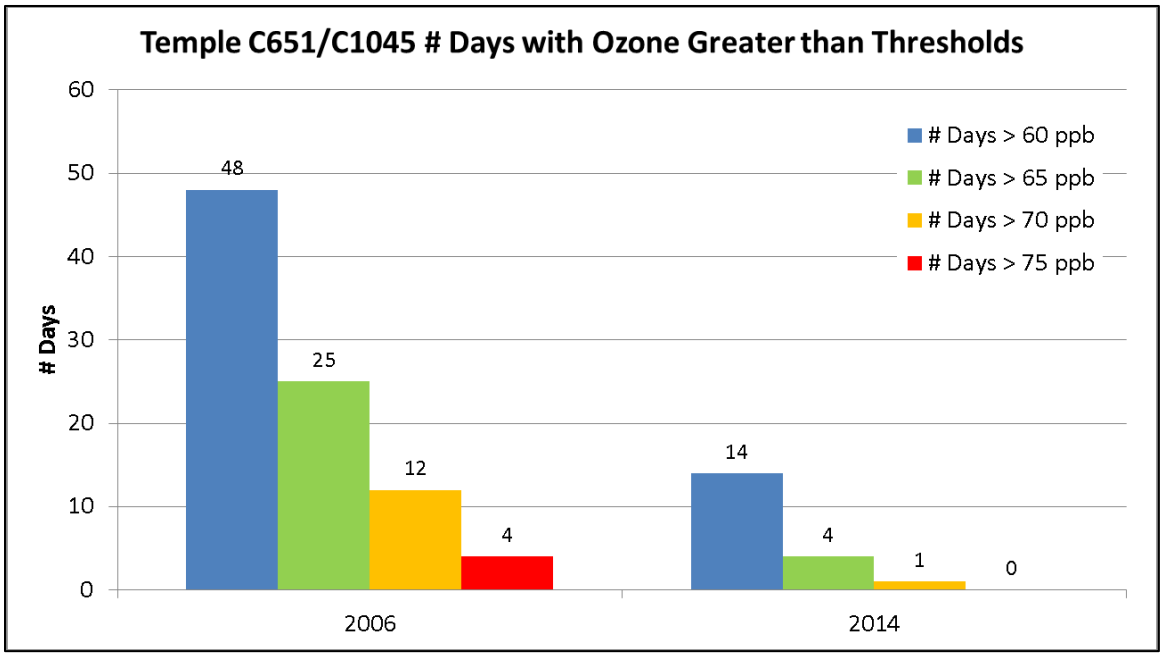

Figure 5-2. Number of days per year with ozone concentration greater than threshold levels at the Temple CAMS 651 (2006) and Temple Georgia CAMS 1045 (2014) monitors.

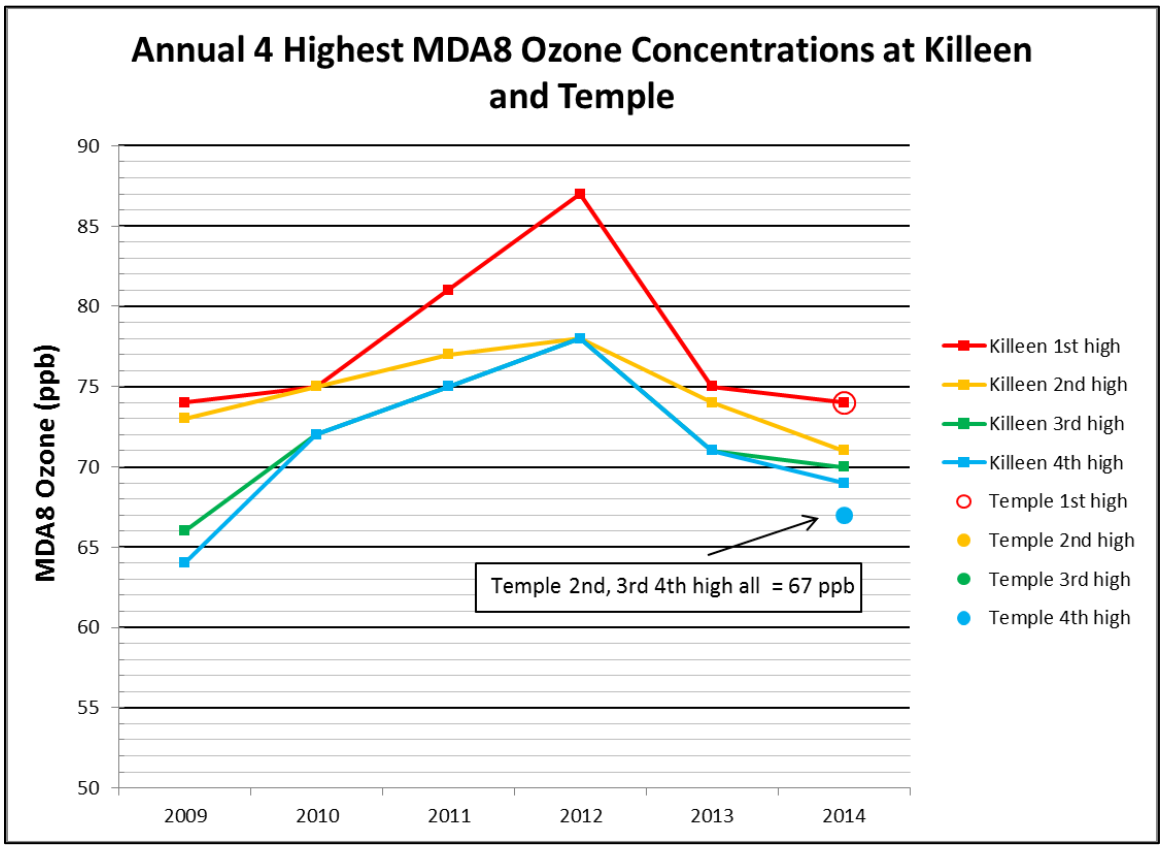

Figure 5-3. 2009–2014 four highest daily max 8-hour average ozone concentrations at Killeen (CAMS 1047) and 2014 four highest MDA8 ozone concentrations at Temple Georgia (CAMS 1045).

5.1.2 By Month

The distribution of high ozone days during 2010-2014 by month is presented in Figure 5-4. At all ozone threshold levels, a double peak is observed, with a local minimum in the number of days with MDA8 ozone exceeding the thresholds in July. This bimodal pattern is consisted with what has been observed and reported on in other regions of Texas such as Waco (McGaughey et al., 2010; 2012); and Northeast Texas, (Kemball-Cook et al., 2014) and is attributed to large-scale southerly winds bringing relatively clean maritime air from the Gulf of Mexico into Texas during July. During the other time periods, Texas is more frequently influenced by continental air that is more polluted than the maritime air and arrives from regions generally to the north and east.

The only months with MDA8 > 75 ppb are June, August and September, with the most days above that threshold occurring in August. The months most frequently experiencing MDA8 ozone > 60 ppb are September, May and then August. All other months that are not shown have no days exceeding any of the thresholds.

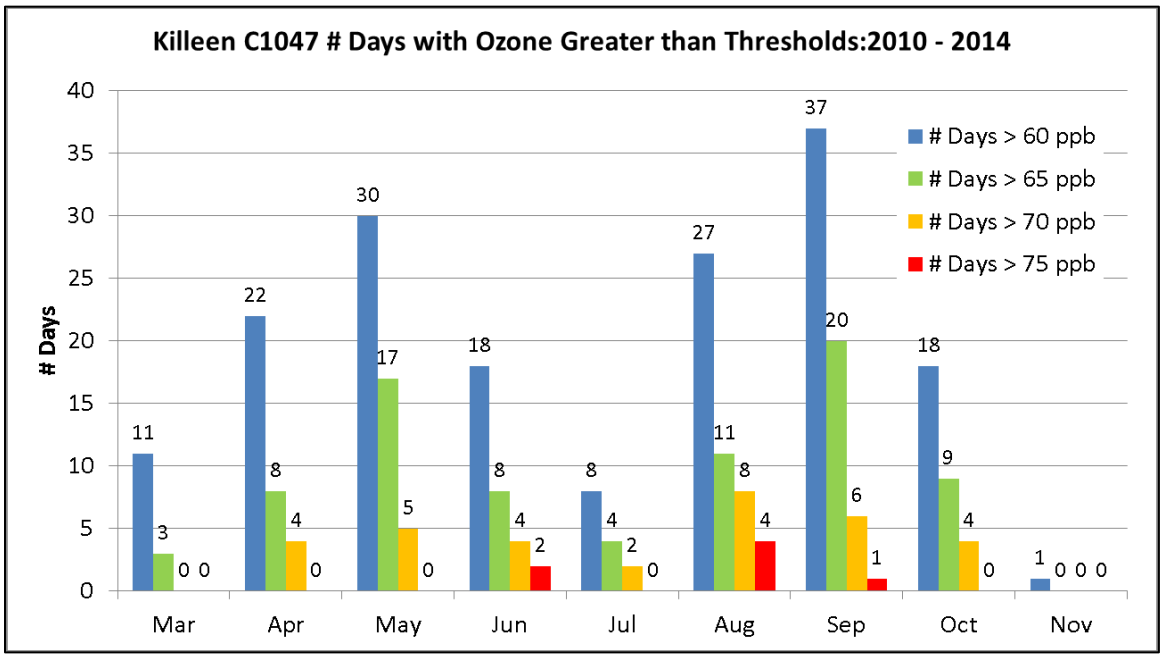

Figure 5-4. Killeen CAMS 1047 distribution of high ozone days in 2010-2014 by MDA8 threshold and by month.

The number of days per month experiencing high ozone at Temple is presented in Figure 5-5 and Figure 5-6, at Temple Georgia CAMS 1045 (2014) and at Temple CAMS 651 (2006), respectively. Since each figure represents a single year of observations, a climatological pattern is not obtained. However, the single-year patterns for the two Temple area monitors are similar to what is observed at Killeen. Note that 2006 was a year with high ozone concentrations, and MDA8 ozone > threshold levels was monitored on many days. In particular, high ozone episodes occurred throughout much of Texas during the first two weeks and last week of June 2006. Temple CAMS 651 July 2006 ozone was lower than June, August,

September, similar to the 2010-2014 pattern at Killeen. 2014 experienced few days with MDA8 ozone > threshold levels at both Killeen and Temple Georgia. At Temple Georgia, the most days per month with MDA8 > all thresholds levels were reported for May, 2014.

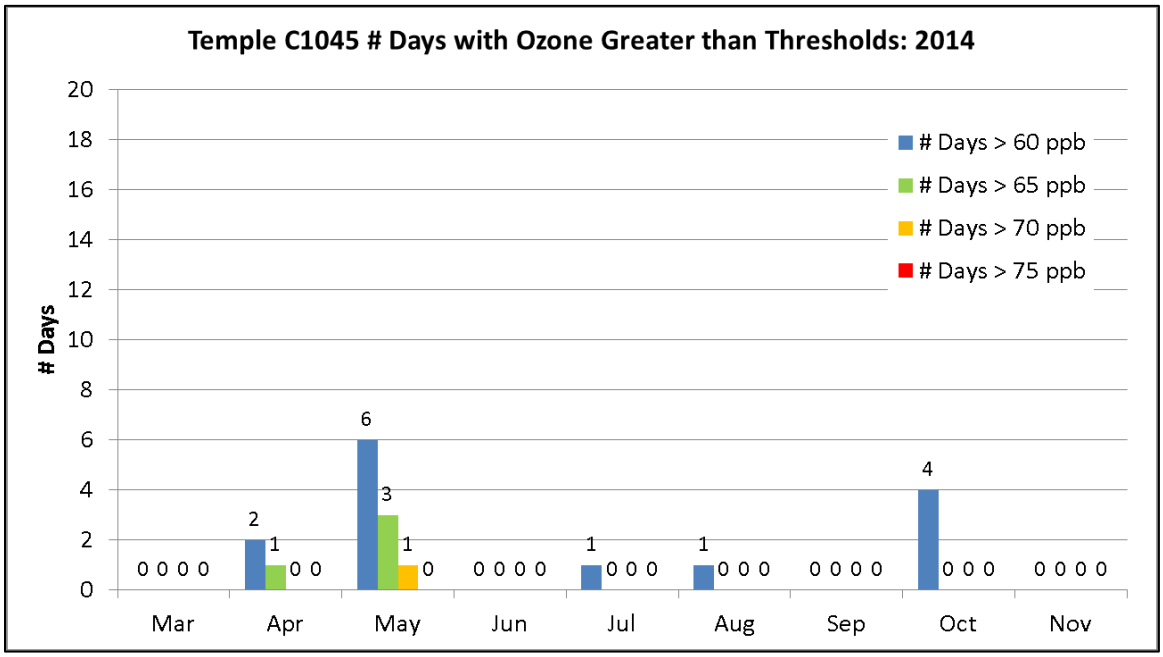

Figure 5-5. Distribution of high ozone days in 2014 by MDA8 threshold and by month at Temple Georgia CAMS 1045.

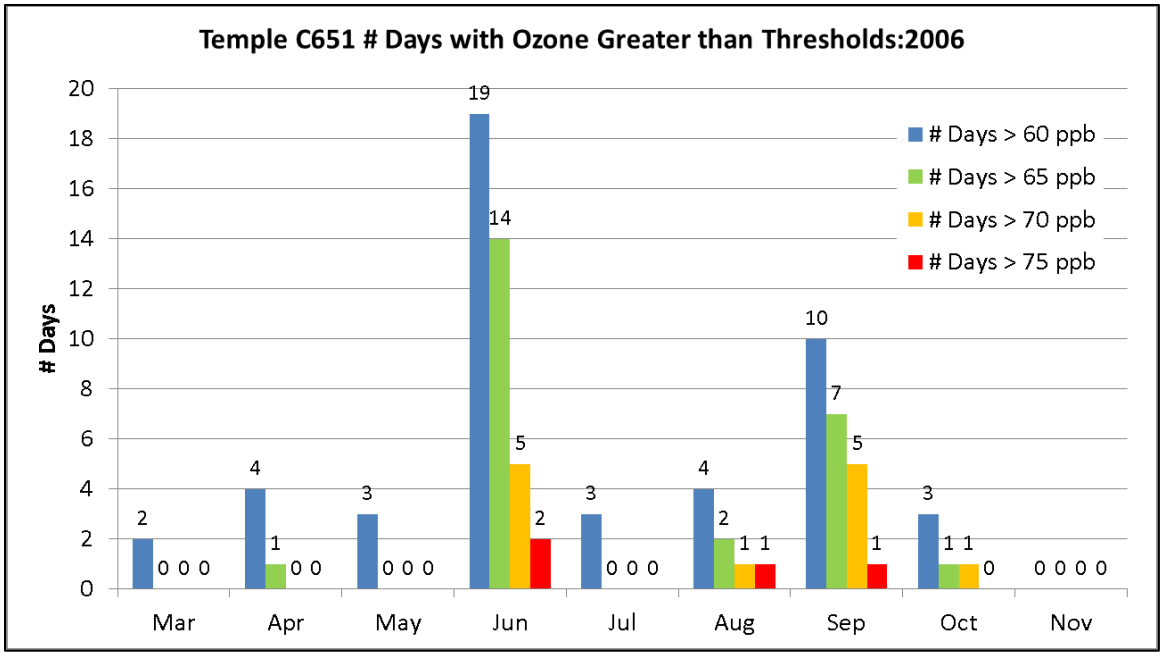

Figure 5-6. Distribution of high ozone days in 2014 by MDA8 threshold and by month at Temple CAMS 651.

5.1.3 By Time of Day

A comparison of the time of day when peak ozone concentrations occur for different ozone threshold levels can help shed light on emissions sources and regions that may contribute to high ozone at those different levels. Since ozone formation requires sunlight, ozone concentrations typically increase during the morning hours, remain elevated throughout afternoon, and then decrease in the later afternoon and evening. If ozone is formed in one location and is transported to another location by winds, peak ozone concentrations at the downwind location may be experienced later in the day due to the transit time of the ozone plume. Thus, the timing of peak ozone concentrations may help determine if ozone transport contributed to high ozone at a particular location.

Figure 5-7 presents the number of days for which MDA8 ozone exceeded the four thresholds by starting hour of the MDA8 ozone calculation. The MDA8 is an 8-hour average of 1-hour ozone concentrations and is identified by the first hour of the 8-hour average. For example, hour 11 in Figure 5-7 refers to the MDA8 ozone being based on averaging the 1-hour ozone concentrations from 11 am to 6 pm and is the most frequent 8-hour averaging time period at all thresholds. MDA8 ozone concentrations based on the eight hours from 10 am - 5 pm, were the next most frequent, followed by noon – 7 pm. Other time periods were less frequent or never occurred. There is no clear difference in the distribution of the starting hour of MDA8 for days with different MDA8 ozone thresholds, suggesting that similar factors may be influencing 8-hour ozone concentrations at all levels.

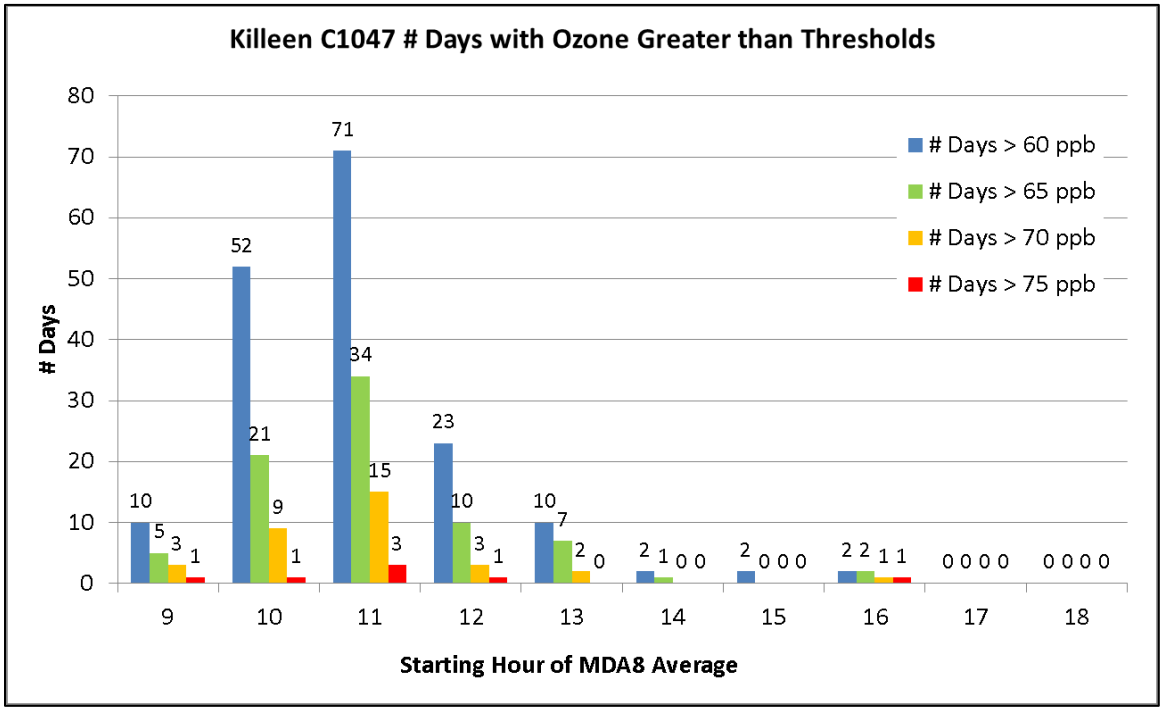

Figure 5-7. Killeen CAMS 1047 distribution of high ozone days by starting hour of MDA8.

Figure 5-8 and Figure 5-9 present the analogous analysis for Temple Georgia CAMS 1045, and Temple CAMS 651, respectively. The results for both Temple monitors are the same as for Killeen, with 11 am – 6 pm being the most frequently occurring time span for the MDA8 calculation, followed by the time spans shifted one hour before or one hour after.

Figure 5-10 compares the distribution of days with MDA8 > 60 ppb and MDA8 ≤ 60 ppb by starting hour of the MDA8 averaging period. For both MDA8 threshold levels, the most frequent averaging period is 11 am to 6 pm and the distribution over the other averaging periods is very similar, suggesting that similar factors may be affecting ozone at both threshold levels

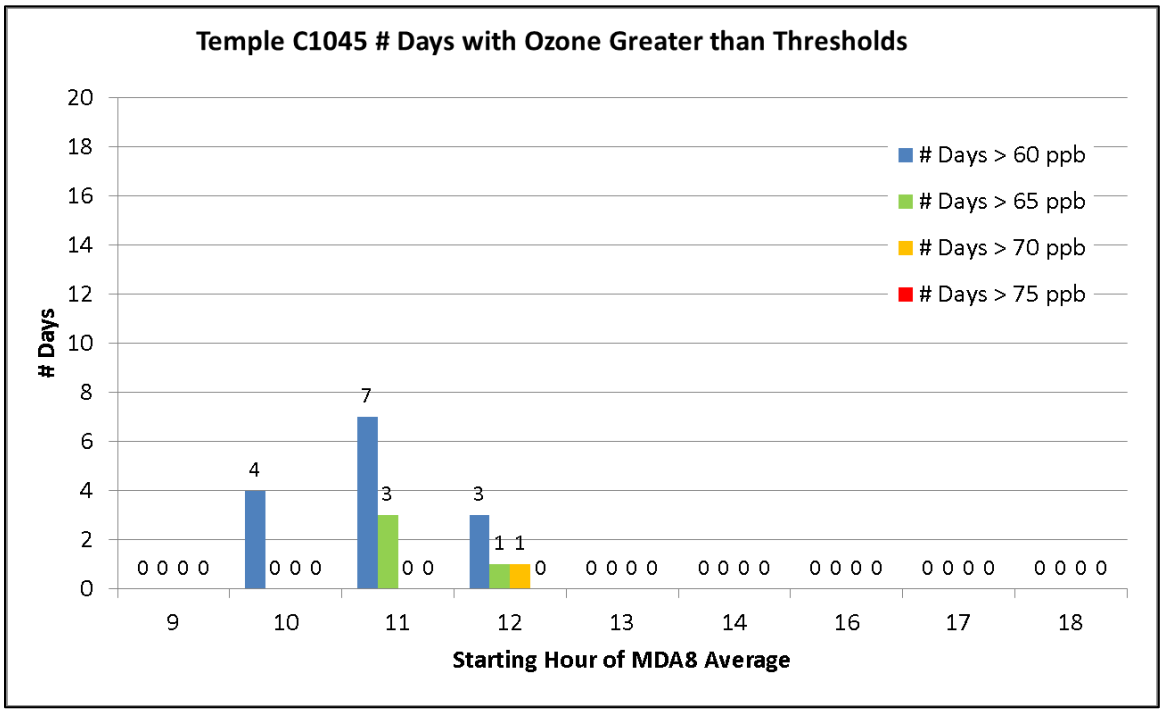

Figure 5-8. Temple Georgia CAMS 1045 distribution of high ozone days by starting hour of MDA8.

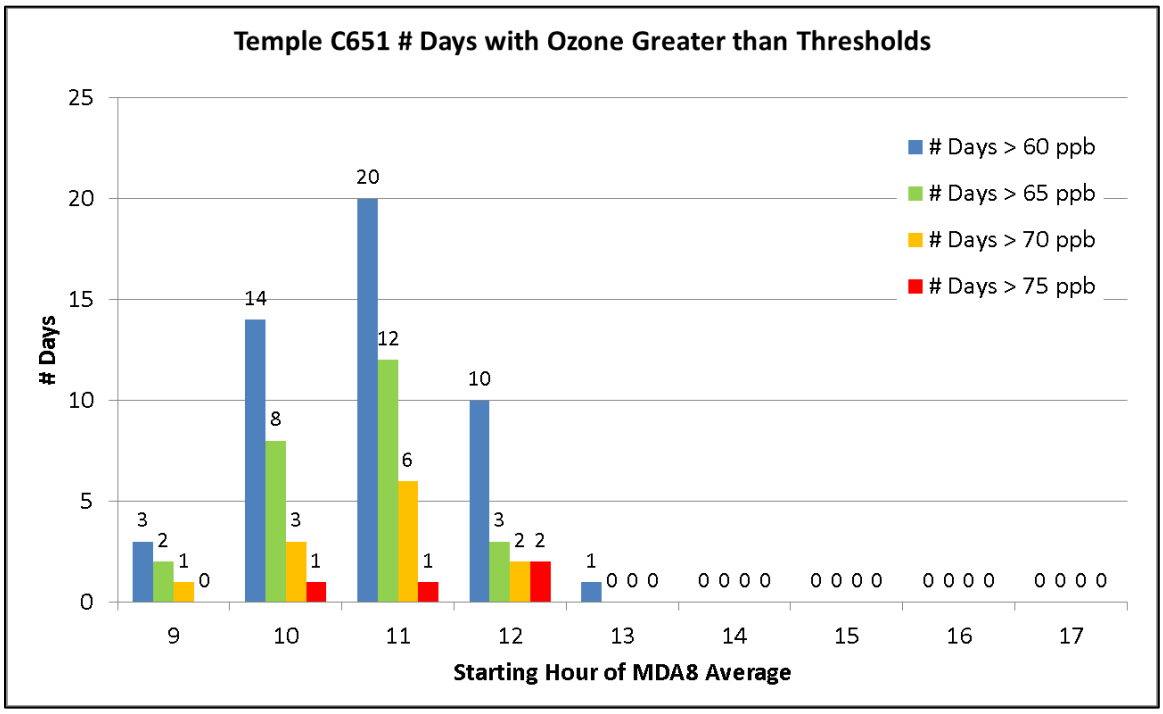

Figure 5-9. Temple CAMS 651 distribution of high ozone days by starting hour of MDA8.

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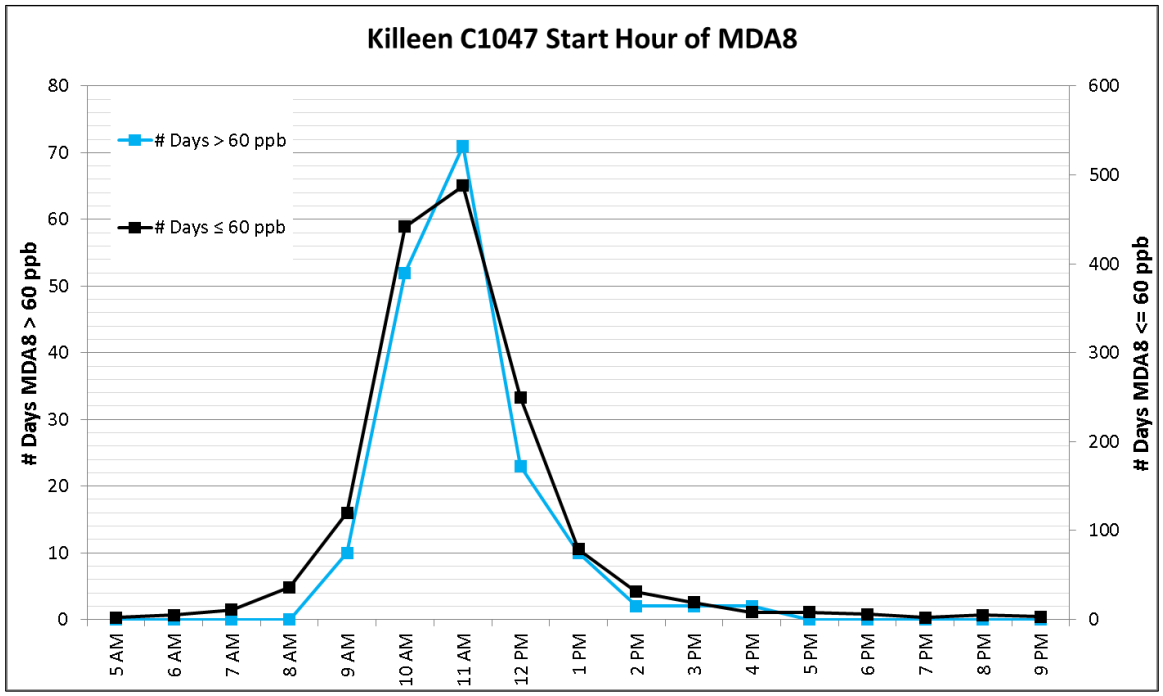


Figure 5-10. Starting hour of maximum daily 8-hour average at Killeen for days with ozone ≤ 60 ppb compared to days with ozone > 60 ppb.

An alternative method using the daily temporal pattern of ozone to attempt to determine possible emissions sources that may be contributing to high ozone - and a method that may be better suited to assessing local impacts - is to examine temporal properties of 1-hour ozone. The hour of maximum daily 1-hour ozone (MDA1) concentration differentiated by different threshold levels is analyzed in Figure 5-11.

For days with MDA8 ozone > 60 ppb, 65 ppb, and 70 ppb, the peak daily 1-hour ozone (MDA1) most often occurs at 4 pm, which is later than the hour of MDA1 for days with MDA8 ≤ 60 ppb. This may suggest that days with MDA8 > 60 ppb are more influenced by transport than days with MDA8 ≤ 60 ppb. There is a local minimum in the number of days with MDA1 occurring at 3 pm for high ozone days, and local maxima at 1 or 2 pm and 4 or 5 pm, in contrast to the MDA8 ≤ 60 ppb days which have a single maximum at 3 pm. The reason for the double peak in hour of MDA1 is not clear, but may suggest two different types of influences, and is investigated further in Section 5.3.

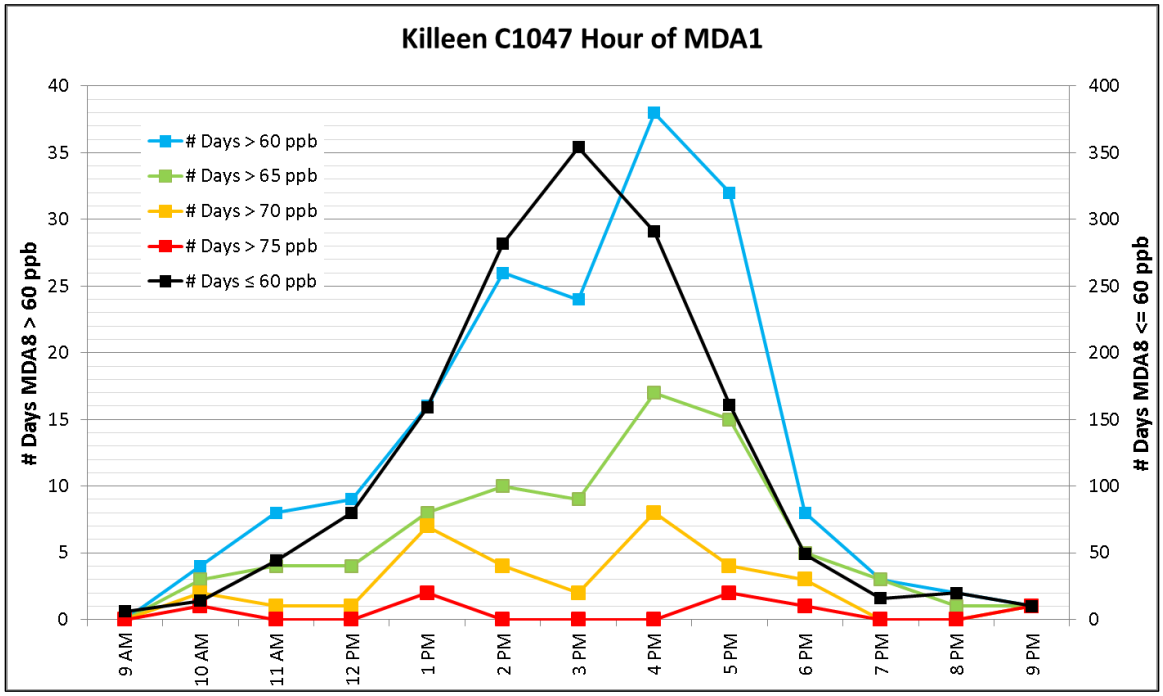


Figure 5-11. Hour of maximum daily 1-hour average ozone concentration at Killeen for different threshold levels

5.1.4 By Day of the Week

In designing ozone control strategies for an area, it is important to understand the role played by on-road mobile sources. In areas where on-road vehicles play a key role in determining ozone levels, the typical diurnal cycle of ozone and precursors for weekend days may be different from that of weekdays due to differences in driving activity. The main differences are the absence of morning and evening commute periods on weekends and less heavy-duty truck traffic on weekends. NOx differences between weekday and weekend are most pronounced during morning and afternoon commute hours. We might expect that since weekday NOx and VOC emissions from traffic are higher than weekend emissions, ozone would be consistently higher than on weekends. However, in some urban areas, the daily maximum ozone concentrations are higher on weekends than on weekdays; this is known as the weekday/weekend effect.

Ozone formation depends on the amount of NOx and VOC present as well as on the ratio of VOC to NOx, where the ratio is taken in terms of ppbC/ppb. When the VOC/NOx ratio is higher than about 10, ozone formation is limited by the amount of available NOx and reducing NOx tends to decrease peak ozone concentrations. However, if the VOC/NOx ratio is less than about 7, reducing NOx tends to increase ozone levels, and the area is said to be VOC-limited. In this situation, ozone is suppressed in the urban area due to titration by large amounts of fresh NO emissions. When NOx emissions are reduced, the suppression of ozone by NO is lessened and ozone increases. Since the KTF Area is NOx-limited, (Grant et al., 2015) lower NOx emissions on weekends might be expected to reduce ozone formation on weekends.

On-road mobile sources were shown by Grant et al. (2015) to be the largest source of NOx in the KTF counties comprising 37% of the total NOx inventory for the 7-county area in 2012. Since on-road mobile sources are the largest local NOx source category, a day-of-the-week analysis is performed in this section. This type of analysis does not differentiate between locally-formed or transported ozone due to on-road mobile sources (or other day-specific emissions source categories).

The number of exceedance days was normalized to account for the fact that there are 5 weekdays compared to only 2 weekend days per week. We divided weekend counts of days above the threshold by 0.4 (70 weekend days divided by 175 weekday days from March through October). Figure 5-12 shows that at all threshold levels, a normalized week day is more likely to experience high ozone than a normalized weekend day at the Killeen monitor. However, the differences between weekday and weekend counts are minimal at all but the > 65 ppb threshold. The statistical significance of this result is assessed later in this Section. The magnitude of the weekday/weekend difference is therefore relatively small, and may be confounded by carry-over of ozone and precursors across days.

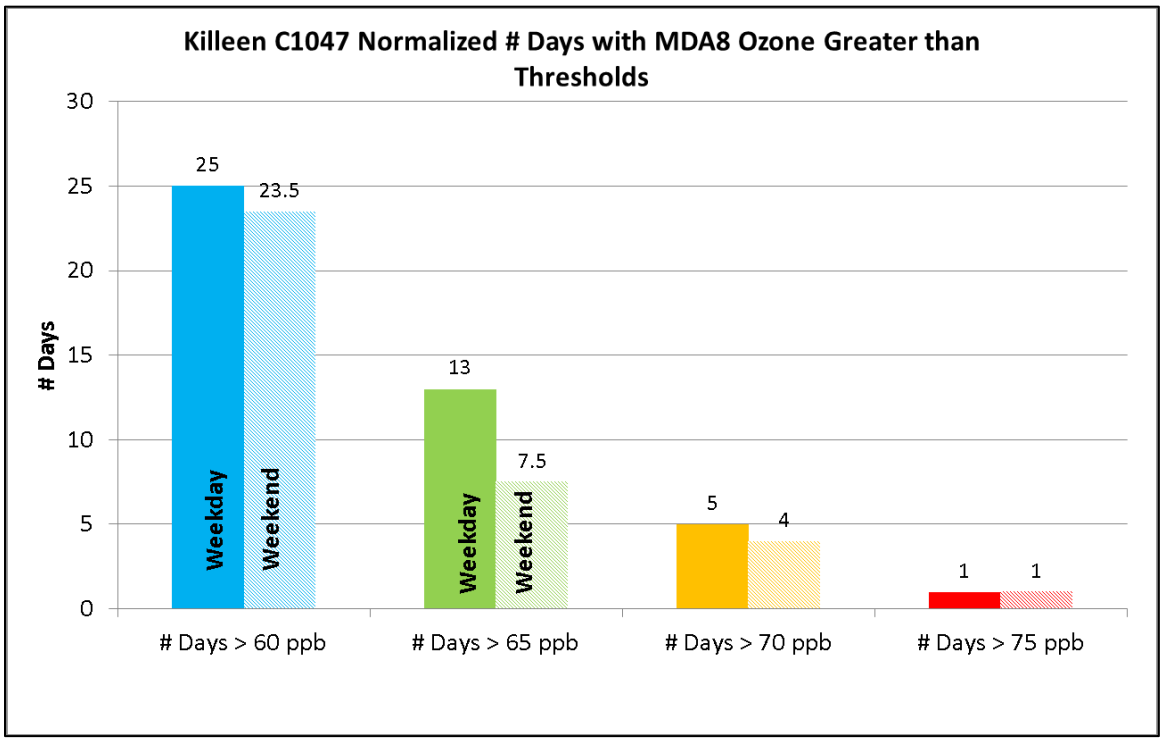


Figure 5-12. Weekday-weekend normalized frequency of exceedance days by threshold level at the Killeen monitor.

Figure 5-13 presents the number of days exceeding each threshold level by individual day-of-the-week during 2010–2014 for all months of the year. For MDA8 > 60, 65, and 75 ppb Wednesdays experienced the most days exceeding those thresholds. For MDA8 > 60, 65, and 70 ppb, Sundays experienced the fewest days exceeding those thresholds.

The next section examines whether the variation in the number of high ozone days by day-of-the week could have easily occurred by chance or is more likely indicative of a response to day-specific emissions variations such as higher NOx emissions from on-road mobile sources during weekdays than weekends.

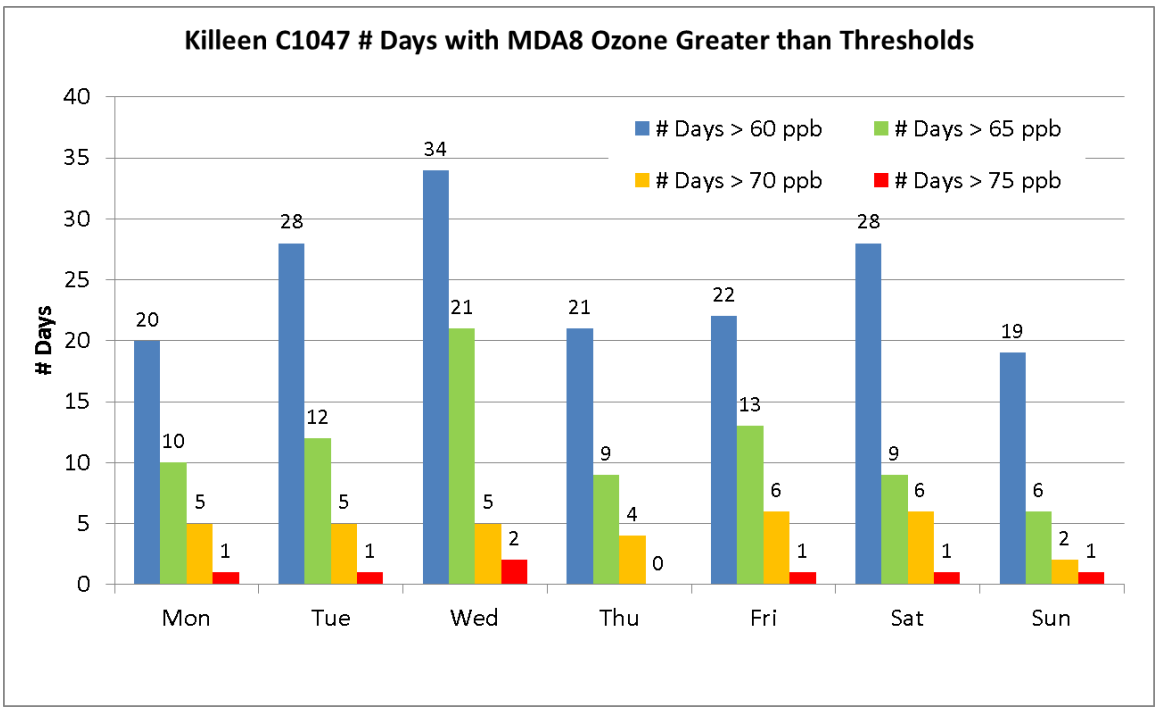


Figure 5-13. Number of days with MDA8 ozone greater than thresholds shown by day of the week: 2010-2014 at the Killeen monitor.

5.1.4.1 Statistical Significance of the Day-of-the-Week Results

To determine if the day-of-the week results in Figure 5-13 could easily have occurred by chance, a statistical significance analysis is presented in this section. The statistical analysis is restricted to the results for the 60 ppb and 65 ppb threshold levels, since at the higher threshold levels MDA8 > 70 and 75 ppb, there are too few days to perform a robust analysis.

At the 60 ppb threshold, there were a total of 172 days with MDA8 ozone exceeding this concentration during 2010 to 2014 and at the 65 ppb threshold there were a total of 80 days with MDA8 ozone exceeding this concentration over the same time period. The total number of days above the threshold is referred to as "N" in the following analysis.

To perform the statistical analysis a "null hypothesis" is defined, and in this case, the null hypothesis is: "There is no day-of-the-week effect; each day of the week is equally likely to experience high ozone (i.e. MDA8 ozone > 60 or 65 ppb), and the observed variation in number of high ozone days is due to chance alone."

Since the null hypothesis states that there is no day-of-the-week effect, any potential "carry-over" effects (i.e., lingering effects of higher ozone or emissions on a particular day affecting ozone on the following day) are implicitly assumed to show no day-of-the-week variation either.

To ascribe statistical significance to the results, a significance level must be set, which is typically set at 5% (Wilks, 2011). If the probability of observing an effect given that the null

hypothesis is true (p-value) is less than 0.05 (=5%) then the results are considered statistically significant. In this case, the p-value is the probability of each day-of-the-week experiencing the observed number of high ozone days assuming that there is no day-of-the-week effect.

The discrete probability distribution for the number of high ozone days to occur on a particular day-of-the-week given "N" total high ozone days throughout the 2010-2014 time period, and assuming no day-of-the-week effect, (and therefore a 1/7 chance of any of the total "N" high ozone days occurring on any particular weekday), is given by a binomial distribution with parameters:

N = total number of high ozone days from 2010-2014 (= 172 days or 80 days)

P = probability that any particular day-of-the-week will be experience the high ozone (= 1/7)

From these parameters the statistical mean (μ), variance (σ^2) and standard deviation (σ) can be calculated:

mean: $\mu = NP$

variance: $\sigma^2 = NP(1-P)$

deviation: $\sigma = \sqrt{NP(1-P)}$

Table 5-1 presents the calculated statistical distribution measures for the observed MDA8 > 60 ppb and > 65 ppb thresholds for Killeen 2010-2014 data.

Table 5-1. Statistical measures for MDA8 > 60 ppb and MDA8> 65 ppb based on binomial distributions.

	MDA8 > 60 ppb	MDA8 > 65 ppb
N = Total Number of Days with MDA8 > threshold during 2010 - 2014	172	80
Mean # of days expected for each individual day-of-the-week (μ)	24.6	11.4
σ (= standard deviation = binomial random deviation from mean value)	4.6	3.1
Mean - 2 σ	15.4	5.2
Mean + 2 σ	33.7	17.7
Probability (P)	1/7	1/7

Figure 5-14 shows the observed number of days with MDA8 > 60 ppb for each day of the week (same as in Figure 5-13) superimposed on the binomial probability distribution for that particular number of total days of MDA8 > 60 ppb from 2010 -2014 at Killeen. The 2σ level shaded in gray corresponds to the range which bounds 95.4% of the number of possible occurrences for any particular day-of-the-week. Values outside the light gray bars are less than 5% likely to have occurred by chance. Since Wednesdays experienced 34 days with MDA8 > 60 ppb, and this number lies above the mean plus 2σ threshold, there is less than a 5% chance that this large number of MDA8 > 60 ppb days occurred by chance. Note that the p-value is less

than 0.05 and the result is considered statistically significant at the 5% significance level. Statistical software was employed to calculate the precise probabilities for each of the days-of-the-week experiencing at most or at least the observed number of occurrences of MDA8 > 60 ppb, these results are shown in

Table 5-2, and are based on the binomial probability formula[26]. Therefore, the high number of days with MDA8 > 60 ppb occurring on Wednesdays is unlikely to be due to chance alone and therefore is likely to be attributable to a day-of-the-week-specific emission phenomenon. The lower number of days occurring on Sundays is within two standard deviations of the mean, so is not considered statistically significant at the 5% significance level.

Similarly, Figure 5-15 shows the observed number of days with MDA8 > 65 ppb for each day of the week (same as in Figure 5-13) superimposed on the binomial probability distribution for that particular number of total days of MDA8 > 65 ppb from 2009 -2014 at Killeen. Again, the results for Wednesday are the only statistically significant results at the 5% significance level, as reported in Table 5-3, along with probabilities for the other days of the week.

The analysis shows that there was only a 5% chance (Table 5-3) that the low number of days with MDA8 > 65 ppb occurring on Sundays could be due to chance alone. Therefore, a day-of-the-week effect approaches but narrowly does not achieve statistical significance at the 5% significance level on Sundays. Therefore, we analyzed the weekday/weekend results using a second statistical technique.

[26] Binomial Probability Formula:

$$P\ (k\ out\ of\ N) = \frac{N!}{k!\ (N-k)!} x\ p^k x\ q^{N-k}$$

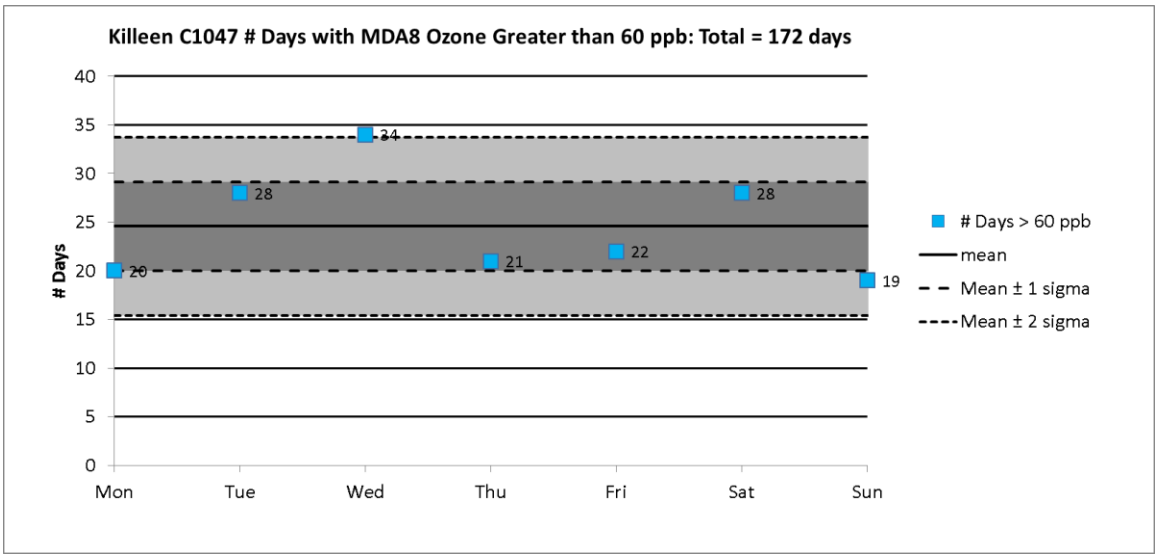


Figure 5-14. Probability distribution (mean, σ and 2σ) for total # of 2010-2014 MDA8 > 60 ppb occurrences and number of observed MDA8 > 60 ppb occurrences by day-of-the-week.

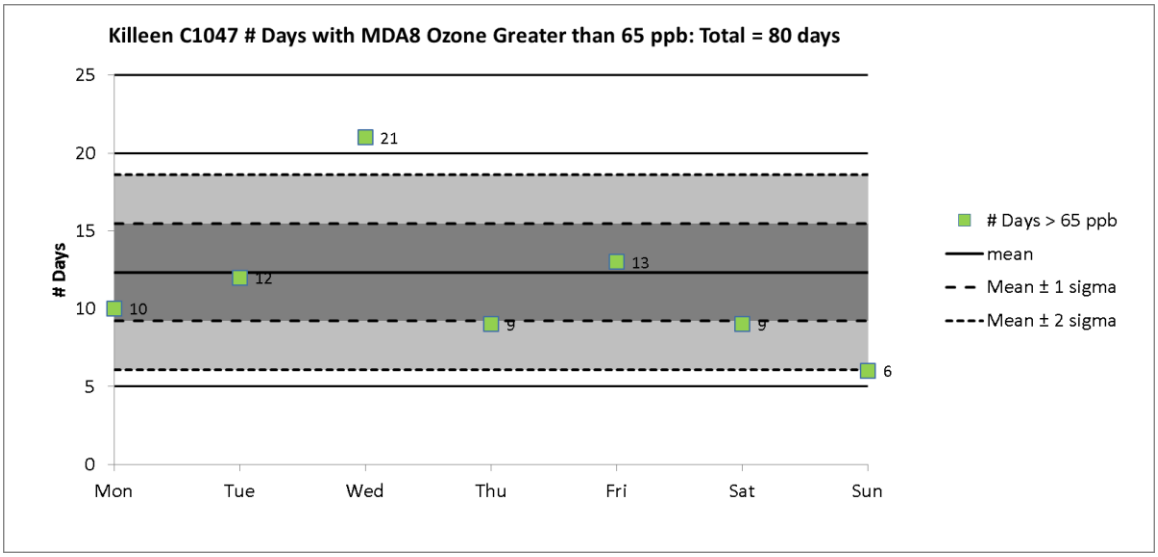


Figure 5-15. Probability distribution (mean, σ and 2σ) for total # of 2010-2014 MDA8 > 60 ppb occurrences and number of observed MDA8 > 65 ppb occurrences by day-of-the-week.

Table 5-2. Probability of occurrence of specific number of days (k) based on binomial distribution (N = 172, p=1/7) for MDA8 > 60 ppb.

Day of Week	Number of Days (k)	Probability at Most k Days	Probability at Least k Days	Statistically significant at 95% Confidence
Sunday	19	13.3%	86.7%	no
Monday	20	18.9%	81.1%	no
Tuesday	28	80.6%	19.4%	no
Wednesday	34	98.1%	**1.9%**	**yes**
Thursday	21	25.6%	74.4%	no
Friday	22	33.4%	66.6%	no
Saturday	28	80.6%	19.4%	no

Table 5-3. Probability of occurrence of specific number of days (k) based on binomial distribution (N = 80, p=1/7) for MDA8 > 65 ppb.

Day of Week	Number of Days (k)	Probability at Most k Days	Probability at Least k Days	Statistically significant at 95% Confidence
Sunday	6	5.0%	95.0%	no
Monday	10	39.7%	60.3%	no
Tuesday	12	64.6%	35.4%	no
Wednesday	21	99.8%	**0.2%**	**yes**
Thursday	9	27.7%	72.3%	no
Friday	13	75.3%	24.7%	no
Saturday	9	27.7%	72.3%	no

An alternative statistical test of the weekly frequency distribution is to construct a Pearson's chi-squared (χ^2) test comparing the observed number of days greater than the threshold with the "expected" or mean number of days greater than the threshold if there was no variation. A two-tailed test was selected, since there could be more or fewer observed days greater than the threshold, and a confidence level of $\alpha = 0.05$ (95% confidence) with six degrees of freedom was established, since there are seven categories (days). Based on those parameters the critical value for the test is 14.5. The computed χ^2statistic for the 65 ppb threshold was 12.050 (P value = 0.0609) and the computed χ^2statistic for the 60 ppb was 7.477 (P value = 0.2790), implying that both weekly distributions fail to be statistically different from the expected distribution, and the distribution may have occurred by chance alone.

However, since the number of high ozone days on Wednesday was shown in comparison to the binomial distribution to be very unlikely due to chance alone, contingency tables were constructed for each day separately and tested with Pearson's chi-squared statistics. Each 2x2 contingency table for a particular day assessed the frequency of that day experiencing high

ozone day, compared to the frequency of that day not experiencing high ozone, against, for all other days of the week, the frequency of any of those other days experiencing high ozone compared to the frequency of any of those other days not experiencing high ozone. Results of this day-specific chi-squared (χ^2) are shown in Table 5-4 for the MDA8 > 65 ppb threshold, and Table 5-5 for the MDA8 > 60 ppb threshold.

Note that the statistical analysis results using the binomial probability approach and the day-specific χ^2 results are in general agreement. Both show that the observed number of high ozone days experienced on all days except Wednesday and Sunday, could clearly be due to chance, whereas the large number of high ozone days on Wednesdays at both the MDA8 > 60 ppb level and the MDA8 > 65 ppb is less than 5% likely to be due chance alone. The relatively small number of Sundays experiencing high ozone is shown by both methods to be a statistically insignificant result. Again, this does not mean there is no day-of-the-week effect of Sundays. It simply means that the data does not show evidence for a day-of-the-week effect with statistical confidence at the 95% certainty level.

Table 5-4. Chi-squared statistical analysis of days with MDA8 > 65 ppb by day of the week.

	Observed # of Days > 65 ppb	Observed # Days ≤ 65 ppb	Expected # of Days > 65 ppb	Day-specific chi-squared (χ^2)calculated from contingency table*	Significance of Day-specific Results
Monday	10	143	11.43	0.23	not significant
Tuesday	12	141	11.43	0.04	not significant
Wednesday	21	132	11.43	10.11	is significant
Thursday	9	144	11.43	0.65	not significant
Friday	13	140	11.43	0.27	not significant
Saturday	9	144	11.43	0.65	not significant
Sunday	6	147	11.43	3.25	not significant
total	80	991	80.00		

*Significant at the $\alpha = 0.05$ level with 1 degree of freedom. Critical value of χ^2: 3.84

Table 5-5. Chi-squared statistical analysis of days with MDA8 > 60 ppb by day of the week.

	Observed # of Days > 60 ppb	Observed # Days ≤ 60 ppb	Expected # of Days > 60 ppb	Day-specific chi-squared (χ^2)calculated from contingency table*	Significance of Day-specific Results
Monday	20	133	24.57	1.18	not significant
Tuesday	28	125	24.57	0.66	not significant

	Observed # of Days > 60 ppb	Observed # Days ≤ 60 ppb	Expected # of Days > 60 ppb	Day-specific chi-squared (χ^2)calculated from contingency table*	Significance of Day-specific Results
Wednesday	34	119	24.57	5.03	significant
Thursday	21	132	24.57	0.72	not significant
Friday	22	131	24.57	0.37	not significant
Saturday	28	125	24.57	0.66	not significant
Sunday	19	134	24.57	1.76	not significant
total	172	899	172.00		

*Significant at the α = 0.05 level with one degree of freedom, one-tailed test. Critical value of χ^2: 3.84

5.2 Analysis of Wind Directions Associated with High Ozone at Killeen

The analyses in this section focus on determining the wind directions associated with high ozone at the Killeen monitor. Section 5.2.1 presents daytime winds (speeds and directions) differentiated by days with MDA8 > thresholds levels (60, 65, 70, and 75 ppb) and indicates which wind directions are associated with high ozone days. The second analysis focuses on 1-hour ozone concentrations, which in some instances, may better identify potential local source impacts.

5.2.1 Wind Rose Analysis

Wind rose diagrams are used to characterize near-surface wind speeds and directions at a meteorological station. In this section, wind rose diagrams based on 2009–2014 wind data from the Killeen CAMS 1047 station are presented. Winds are binned into speed categories: 0 – 6 mph, 6 – 12 mph, 12 - 18 mph and > 18 mph. Winds are also binned into direction categories in 22.5° increments with 0° corresponding to north. Each direction category defines a "spoke" of the wind rose and is defined so that the spoke length is proportional to the number of hours that the wind blows from that direction. The spokes are colored so that each color represents a wind speed and the area of each color is proportional to the amount of time that the wind is blowing at a particular speed from a given direction. To determine whether particular wind directions are associated with observed high ozone at the Killeen monitor, wind rose diagrams are calculated separately for days with different levels of MDA8 ozone.

Figure 5-16 presents the wind rose diagrams based on the morning (6-11 am) and afternoon (noon-6 pm) winds. In some locations, high ozone may occur on days with shifting winds that transport local emissions away from a region in the morning and re-circulate them back to the region in the afternoon so it is useful to analyze wind rose diagrams for mornings and afternoons separately.

Because most ozone season days at Killeen have MDA8<60 ppb, the wind roses for MDA<60 ppb for both morning and afternoon are nearly identical to the plots for all days. On days with MDA8<60 ppb, winds in both the morning and afternoon are most frequently strong and southerly. Afternoon winds have a southeasterly component more often than a southwesterly component. Winds from the north-northwest occur in both morning and afternoon with lower frequency than southerly winds, and winds from the west and east are relatively rare.

The morning and afternoon wind roses for days with MDA8>60 ppb are similar to the wind roses for MDA8<60 ppb except that when MDA8>60 ppb, lower wind speeds (blue) occur more frequently and the northwesterly wind direction is less prevalent ,while the easterly wind component occurs more frequently. As the MDA8 threshold moves upward from 60 ppb to 70 ppb, the morning wind speeds are lower and the morning wind directions are more evenly distributed around the compass. Southerly winds still occur most frequently at the MDA8>70 ppb level, but northwesterly and easterly winds occur more often than at MDA8>60 ppb. The distribution of afternoon wind directions is similar at MDA8>60 ppb and MDA8>70 ppb, but at 70 ppb, the northeasterly wind direction appears more frequently, and wind speeds are lower. For days with MDA8 ozone > 70 ppb level there are no occurrences of wind speeds > 18 mph.

The wind rose plots for the MDA8>75 ppb threshold are qualitatively different from those of the other thresholds. Southerly and southwesterly winds are absent in both the morning and afternoon, and east-southeasterlies occur relatively infrequently. In the morning, northwesterly and northerly winds were most frequent and northeasterly through southeasterly winds were most prevalent in the afternoon. Both morning and afternoon wind speeds were lower than for any other threshold, with nearly all wind measurements lower than 12 mph (green or blue).

In summary, the wind rose plots for Killeen based on 2009–2014 data show that days with MDA8 < 60 ppb are characterized by strong, southerly winds. Strong winds tend to move ozone and its precursors away from Killeen, while light, stagnant winds allow buildup of ozone and precursors that can lead to higher ozone readings. Strong southerly winds are associated with the flow of relatively clean maritime air from the Gulf of Mexico (see Section 5.4).

As the MDA8 threshold increases, there is a greater tendency for lighter winds and for the wind direction to have a more easterly-northeasterly component. Easterly and northeasterly winds tend to bring polluted air of continental origin into the KTF Area, and these wind directions are associated with high background ozone levels in the KTF Area (e.g. Section 5.4 and Parker et al. 2013). As the MDA8 threshold increases, the wind speeds become slower. Slower winds provide less ventilation and tend to keep ozone and emitted ozone precursors in the KTF Area.

For days with MDA8 > 75 ppb, the winds are slower and afternoon winds are much more frequently from the east and northeast rather than the south or southeast. As the MDA8 threshold increases, differences between morning and afternoon winds grow more pronounced, with morning winds more likely to come from northerly and northwesterly directions at higher levels of the threshold. North and northwesterly morning winds may suggest the importance of local source impacts from Fort Hood or the Killeen urban plume in producing MDA8>75 ppb ozone at Killeen. Note that the MDA8>75 ppb wind rose is based on relatively few days (7) compared to the other plots.

Wind rose plots for the Temple Georgia monitor (see Appendix C) are based on 2014 data only and show that winds were always from the south at all threshold levels. Note that 2014 was a low ozone year at sites throughout East Texas and that there were no days with MDA8 > 75 ppb at Temple Georgia, and only 1 day with MDA8 > 70 ppb. Wind rose plots for Killeen are for the 2009-2014 years combined, so they are not directly comparable to the Temple Georgia plots.

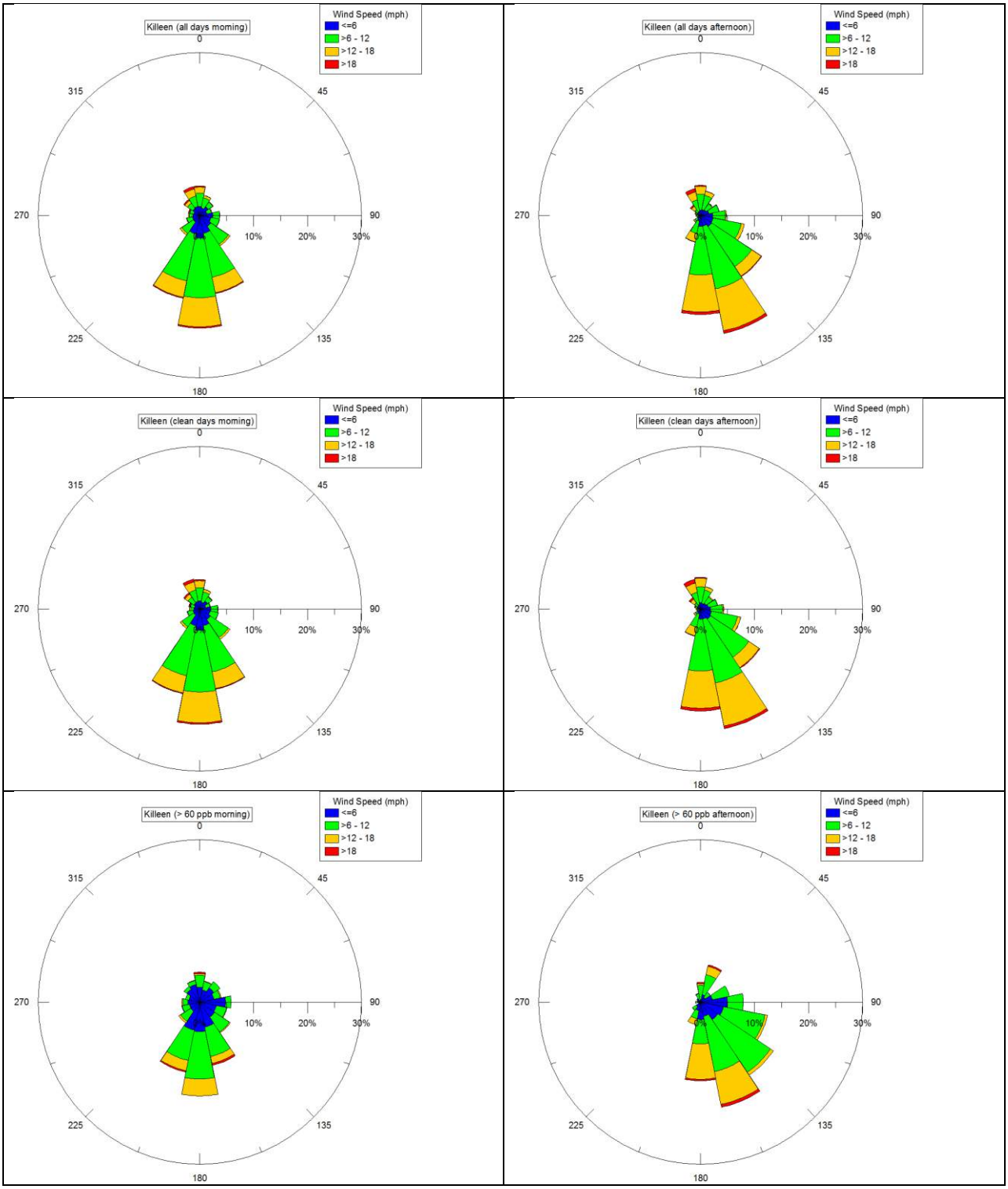


Figure 5-16. Killeen wind rose diagrams for morning hours (6 am- noon; left panels) and afternoon hours (noon – 6 pm; right panels), for different MDA8 ozone thresholds. 2009-2014 data. Upper panels: all ozone season days; middle panels: days with MDA8 ≤ 60 ppb; lower panels: days with MDA8 > 60 ppb.

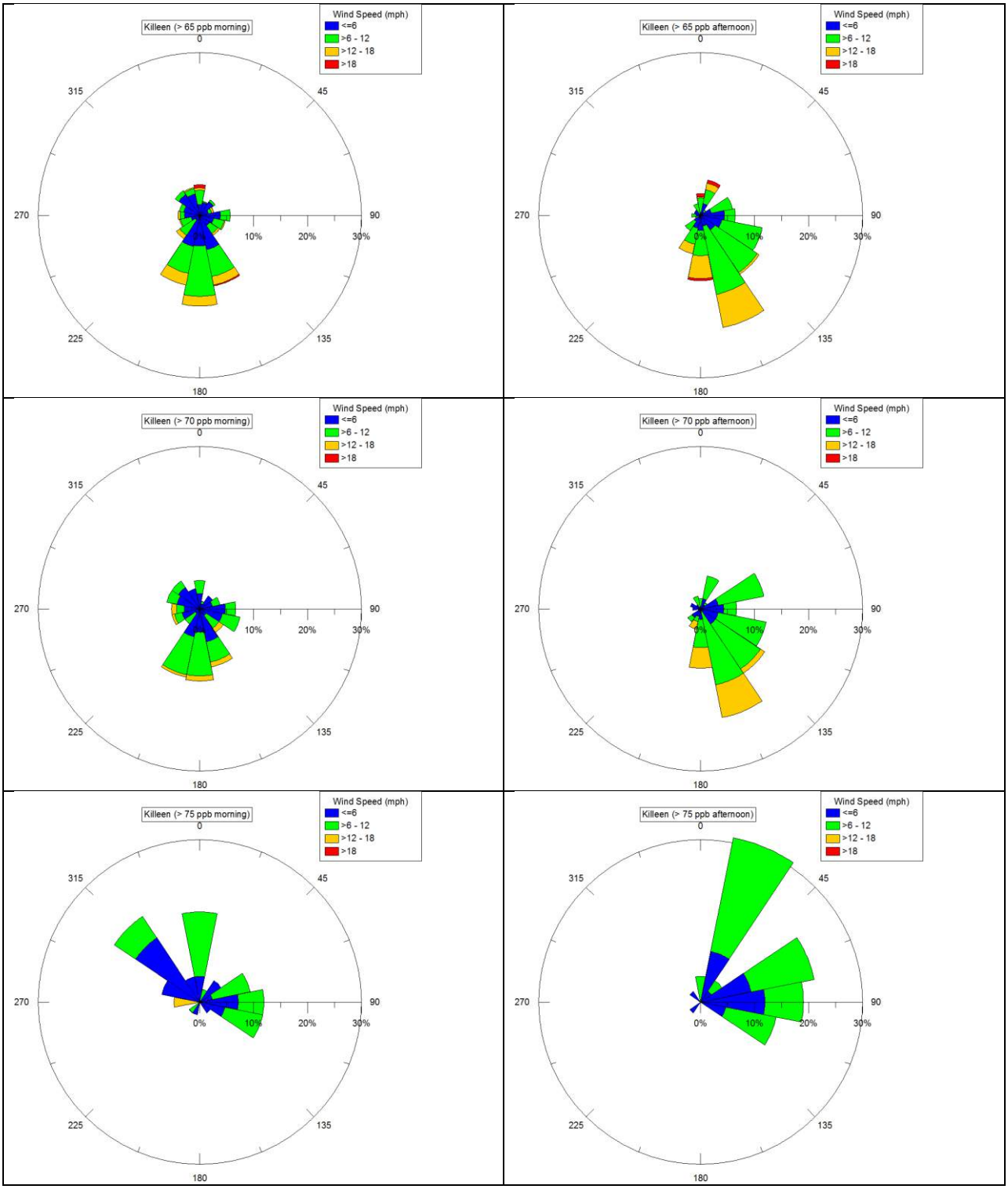


Figure 5-17. Killeen wind rose diagrams for morning hours (6 am- noon; left panels) and afternoon hours (noon – 6 pm; right panels), for different MDA8 ozone thresholds. 2009-2014 data. Upper panels: days with MDA8 > 65 ppb; middle panels: days with MDA8 > 70 ppb; lower panels: days with MDA8 > 75 ppb.

5.2.2 Wind Directions Associated with High 1-hour Ozone Concentrations

Plots showing directions associated with high short-term ozone (1-hr) may be used to identify large local point sources that can influence ozone at a monitor. The Sandow power plant is the only large NOx point source within the KTF Area, as shown in Figure 5-18 (identical to Figure 4-17, and reproduced here for the reader's convenience). There are other large point sources north, east and south of the KTF Area (not shown) that could also potentially affect ozone at Killeen. Other emissions sources that can affect 1-hour ozone concentrations at Killeen are urban plumes from the Austin, Waco, Temple and Killeen urban areas.

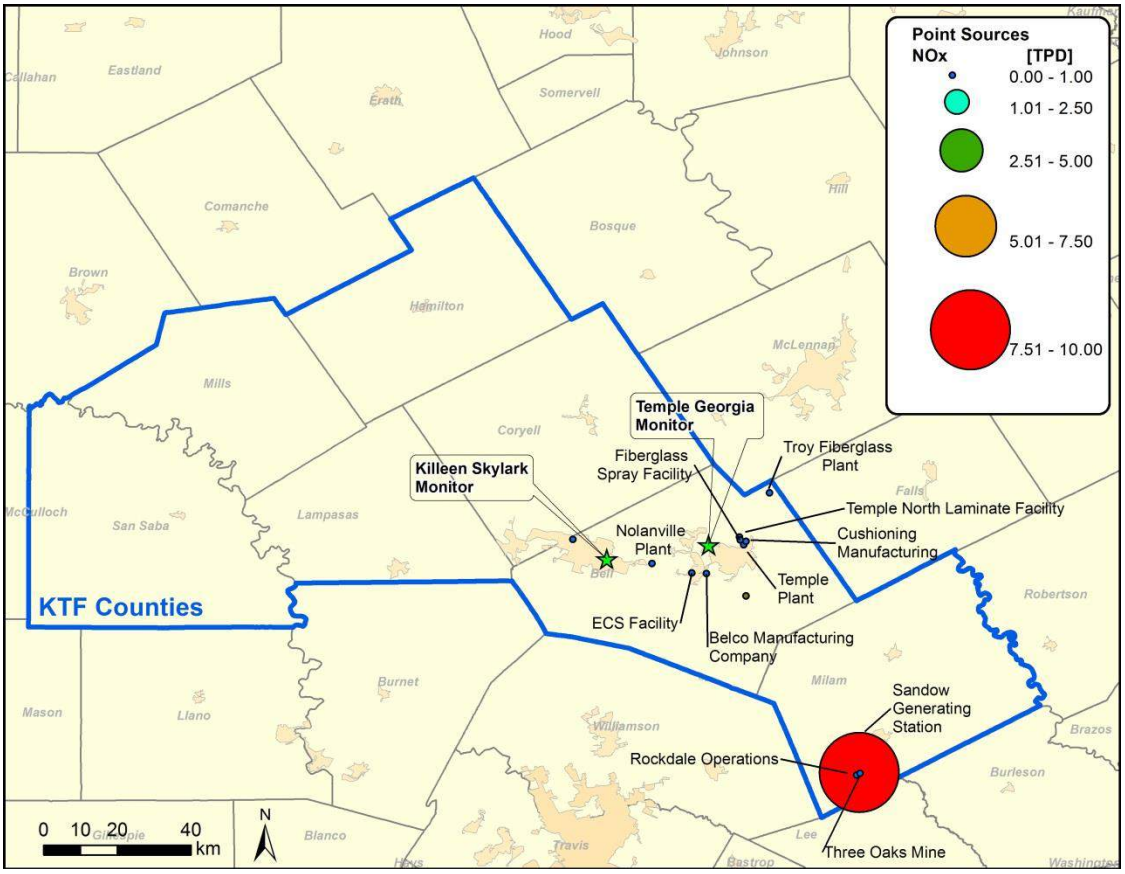


Figure 5-18. Point source NOx emissions.

Plots that show the wind directions at Killeen associated with different levels of 1-hour ozone are presented in Figure 5-19, for 2009–2014. These plots show good agreement with the wind rose plots previously presented, and the HYSPLIT trajectories in the following section. The most frequent wind direction is southerly, followed by southeasterly. As the 1-hour ozone threshold increases to 70 ppb and 80 ppb, the wind direction shifts progressively to more easterly, with northeasterly, easterly, southeasterly and southerly winds all with similar frequency at the 80 ppb level. Sources to the south and southeast of the Killeen monitor include the Austin urban area as well as the Sandow Power Plant. There are only a few hours with 1-hour ozone > 85 ppb at Killeen; there were 14 occurrences in total during 2009-2014, five of which occurred

during a period of northerly winds on a single day (8/10/2012). The emissions source(s) that influence the Killeen monitor are not clear.

Addition of an SO_2 monitor at Killeen or Temple Georgia would facilitate a better understanding of possible source impacts at those monitors. A coal-fired power plant such as Sandow would likely generate measureable SO_2 impacts that would coincide with ozone impacts at distant monitors. Therefore, if an ozone impact is matched in time with an SO_2 impact it would be likely that a coal-fired power plant contributed to the ozone impact.

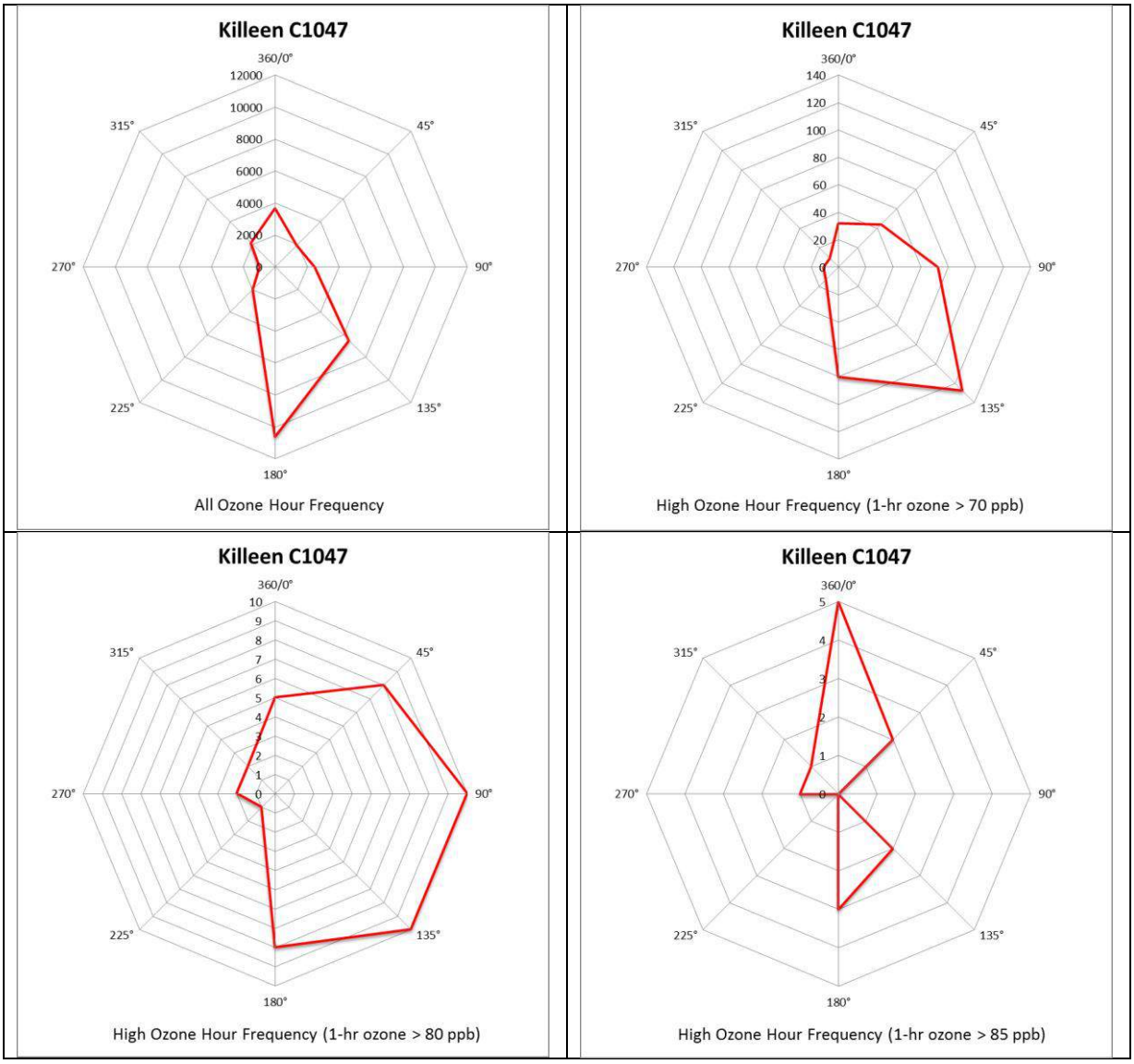


Figure 5-19. Radar plots displaying wind direction associated with different levels of 1-hour ozone.

5.3 Time Series plots for Days with MDA8 > 70 ppb

The objective of this section is to investigate the observed bi-modal pattern in hour of MDA1 reported in Section 5.1.3. In order to investigate this phenomenon, time series plots of 1-hour ozone for individual days are analyzed. To keep the number of time-series analyzed manageable, but still provide a useful analysis, the MDA8 > 70 ppb threshold level was selected. The bi-modal pattern of hour of MDA1 at this threshold was well-defined. There were seven days with MDA1 occurring at 1 pm, only two days with MDA1 occurring at 3 pm and 8 days with MDA1 occurring at 4 pm There were 35 total days with MDA8 > 70 ppb at Killeen over the 2009-2014 time period.

Figure 5-20 to Figure 5-23 present daily time series plots for days with MDA8 > 70 ppb at Killeen. Since the Killeen monitor had relatively few days with MDA8 > 70 ppb during 2009 and 2010, those days are grouped together on the first plot. The second and third plots are for 2011 and 2012 respectively, and the fourth plot presents 2013 and 2014 days combined. Peak 1-hour ozone times are observed prior to and after the 2–3 pm hours for a number of days in the plots as indicated in Figure 5-11. On some days there is a double peak, such as 7/2/2009 and 6/25/2012, while others have an early peak (6/26/2012 and 9/26/2013) or late peak (4/12/2010 and 5/16/2014). The bi-modal pattern is less pronounced for days in 2011.

Performing a high ozone day analysis which would analyze each of these days individually and determine back trajectories for each day to determine source regions that could potentially be transporting ozone precursor emissions to Killeen is outside the scope of this project. This type of analysis would be necessary to determine if the bi-modal pattern in peak 1-hour ozone can be attributed to impacts from different source regions. However some observations can be made from the time series alone. In particular, if a large local source were to create a plume with high ozone concentrations, and that plume were to directly affect an air quality monitor, due to the relatively short plume transit time, and therefore short time for plume dispersion, it is likely the monitor would measure a sudden and often relatively short duration (unless winds were very steady) peak in ozone concentrations. The only day exhibiting this classic signature of a large local source impact is 5/5/2010, with an almost 20 ppb increase over 1 hour. Analysis of the wind direction on this day (not shown) showed that the increase in ozone was associated with a wind shift from southwesterly to southerly, which suggests that the source of the impact was south of the Killeen monitor.

There were a few occurrences of high ozone (i.e. 1-hour ozone > 80 ppb) that were measured early in the day (i.e. by 10 or 11 am). For example: 8/28/2011; 6/26/2012; and 9/26/2013. These days were previously analyzed in a high ozone days analysis (Parker et al., 2013) which is summarized in Section 5.6, and were all shown to be days with high regional ozone and also potentially influenced by local sources.

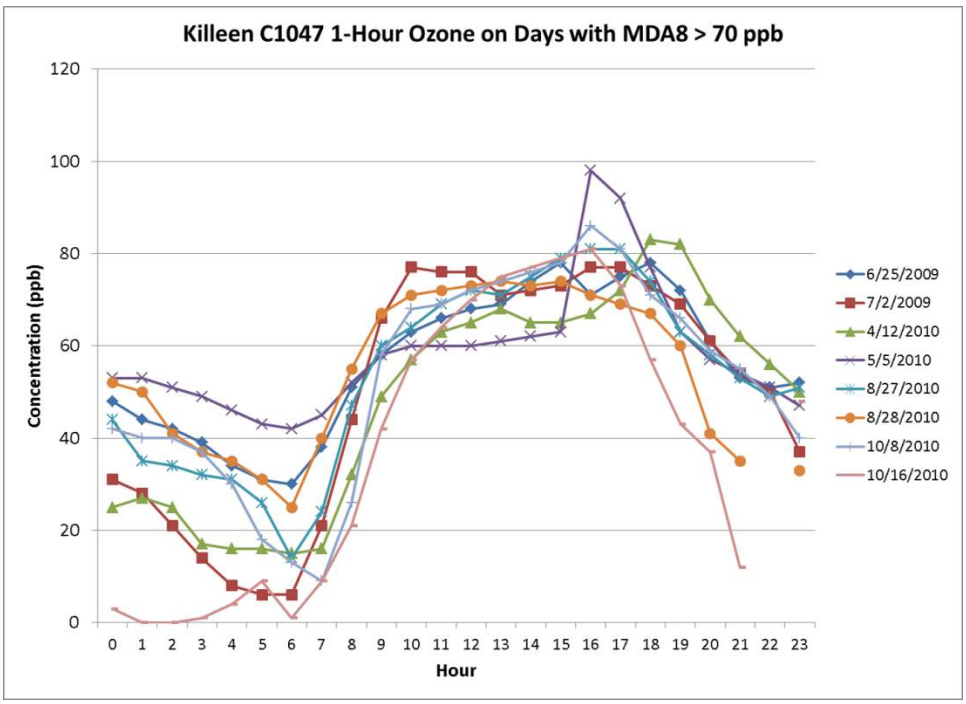


Figure 5-20. Killeen 1-hour ozone on days with MDA8 > 70 ppb in 2009 and 2010.

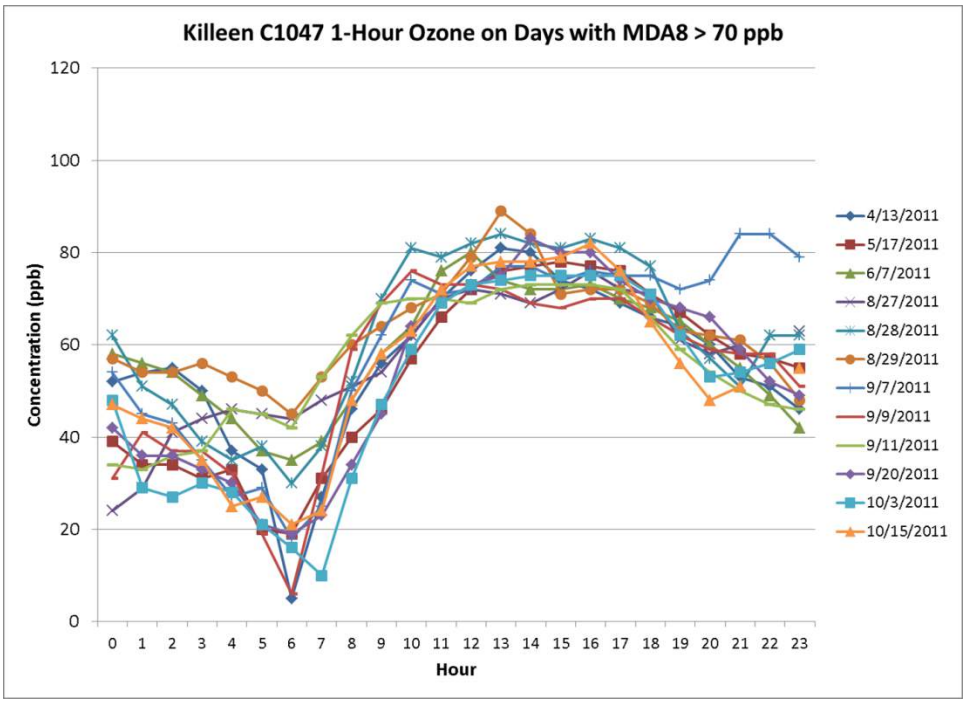


Figure 5-21. Killeen 1-hour ozone on days with MDA8 > 70 ppb in 2011.

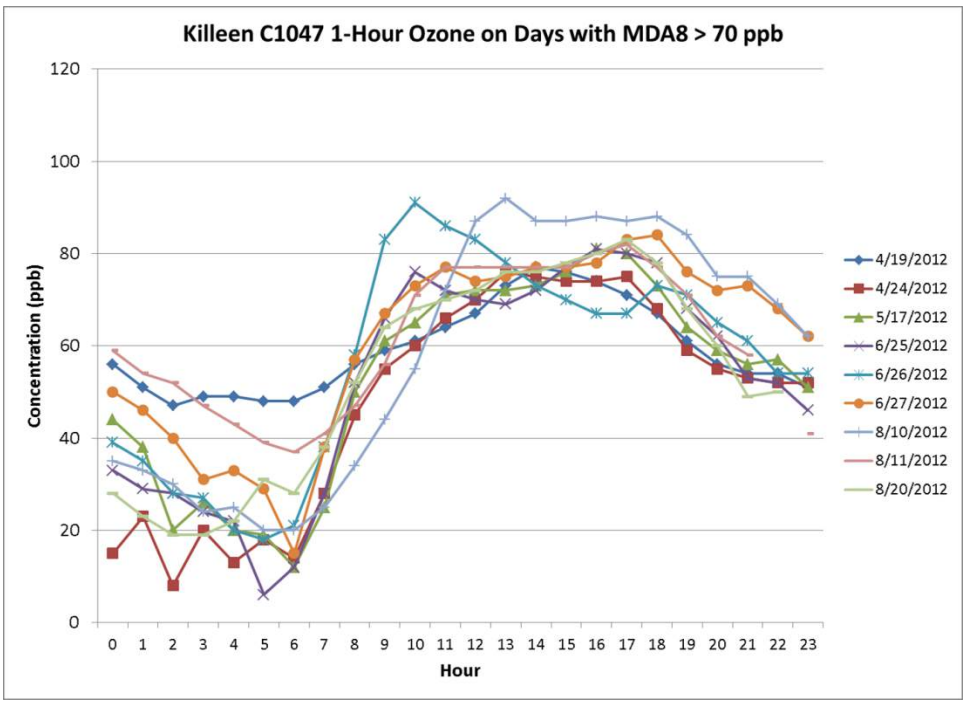


Figure 5-22. Killeen 1-hour ozone on days with MDA8 > 70 ppb in 2012.

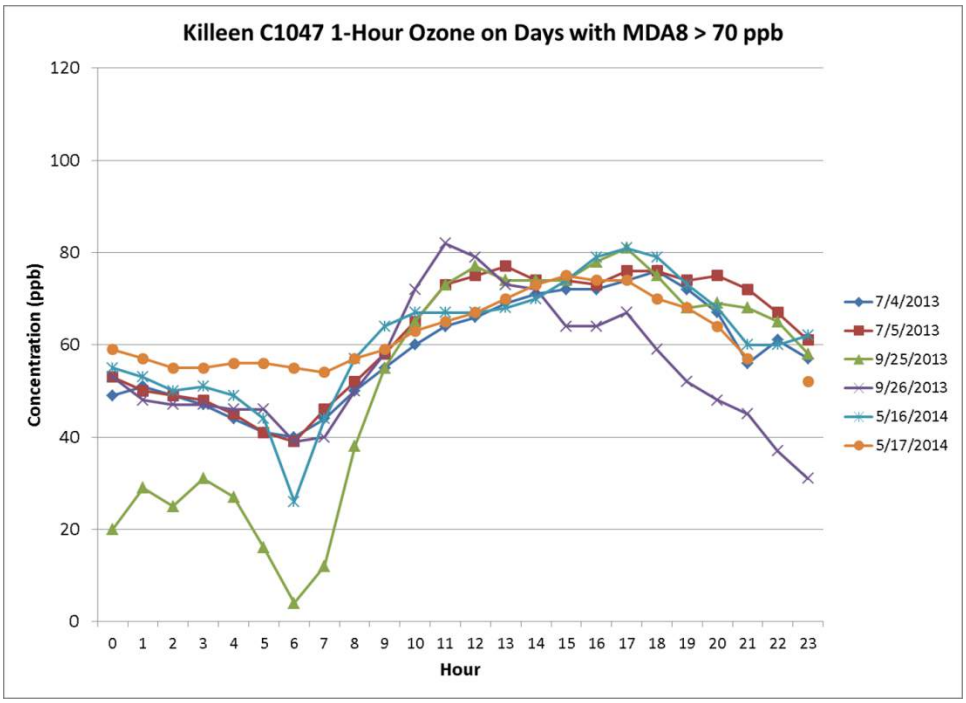


Figure 5-23. Killeen 1-hour ozone on days with MDA8 > 70 ppb in 2013 and 2014.

5.4 HYSPLIT Backward Trajectory Analysis

The purpose of a back trajectory analysis is to estimate the path that an air mass travelled prior to influencing a specific monitor. Backward trajectory plots provide approximate information regarding possible source regions for pollutants transported to a monitor. However they may have considerable uncertainty which grows with increasing trajectory length. Backward trajectories should not be interpreted as giving the precise track of air parcels. Displaying the path of an air parcel without an associated measure of dispersion gives only limited information in terms of attributing source region impacts at a receptor site. Under some meteorological conditions different types of backward trajectories may indicate seemingly contradictory predictions due to inherent differences in the way they are calculated.

Backward trajectories were prepared for each high ozone day for ending altitudes of 100 m, 500 m, and 1,500 m using the on-line tools provided by the NOAA at http://www.arl.noaa.gov/ready/hysplit4.html (Rolph et al., 2013). These tools are based on application of NOAA's HYSPLIT model (Draxler et al., 2013) with archived weather forecast model data from the National Center for Environmental Prediction's EDAS forecast model. Uncertainties are introduced by the spatial and temporal resolution of the three-dimensional gridded EDAS meteorological data and also by the inherent uncertainties in the analyzed meteorological data. Meteorological data are derived by assimilating available high frequency observations such as wind profiler, radar, and aircraft data with modeled predictions. The horizontal spatial resolution is 40 km and the temporal resolution is 3 hours. Large scale weather patterns are likely well-simulated by the meteorological model and HYSPLIT but smaller scale localized weather features may not be captured at the model's spatial and temporal resolution. HYSPLIT backward trajectories are therefore likely to be more accurate on days with strong winds driven by large-scale weather features. Days with light, shifting winds are more likely to have backward trajectories with larger uncertainties than days with strong, steady winds.

Back trajectories on days with strong, steady winds without substantial vertical wind shear may be reasonably accurate, in contrast, back trajectory estimates on days with light, shifting winds or stagnant wind conditions and/or high vertical wind shear may have substantial uncertainty. It is likely, however, that on days with stagnant and/or slow winds, the back trajectories will correctly identify that type of wind regime, however, the specific back trajectory path is likely to be highly uncertain and should not be relied on to determine a specific source region impact.

Differentiating HYSPLIT back trajectory plots by days with different thresholds of MDA8 ozone at Killeen can suggest which emission source regions may be contributing to high ozone concentrations at those different thresholds. Figure 5-24 presents 24-hour HYSPLIT back trajectories for days with MDA8 ozone ≤ 60 ppb (left) and days with MDA8 ozone > 60 ppb (right). Days with higher ozone have shorter trajectories indicating slower wind speeds on those days compared to the days with lower MDA8 ozone. There is a similar spatial pattern in terms of the directions from which air is being transported to Killeen at MDA8 ozone ≤ 60 ppb and > 60 ppb, and the highest density of points is east clockwise to south.

Figure 5-25 differentiates 24 hour HYSPLIT back trajectory plots by increasing levels of MDA8 ozone. The upper left panel of Figure 5-25 presents 24-hour HYSPLIT back trajectories for days with MDA8 > 60 ppb and is a repeat of the data shown in the right panel of Figure 5-24, presented at a more zoomed-in perspective for comparison to the other threshold levels. Raising the MDA8 threshold level from 60 – 70 ppb, shows only few differences in the qualitative nature of the trajectories. The trajectory lengths tend to decrease indicating slower wind speeds, but the directions of transport remain similar. At the MDA8 ozone > 75 ppb level shown in the lower right panel of Figure 5-25, there are only seven back trajectories and they originate from the north on four occasions, the east on two occasions and the south once. This analysis is in agreement with the wind rose analysis and suggests that regions north clockwise through east may contribute to high ozone, and the highest ozone is often associated with transport from the north. An estimate of regional NOx emissions is provided in Figure 5-26, which is a spatial plot of the 2011 NEI NOx emissions by county for Texas. It shows that there are many counties with high NOx emissions circling Killeen at different distances from north clockwise through south to south west, which is in agreement with the directions shown to be transporting air to Killeen on high ozone days. In addition, some 24-hour back trajectories extend further than Texas into states located north and east of Texas; ozone precursor emissions from other states can contribute to high regional background ozone and therefore high ozone days in the KTF Area.

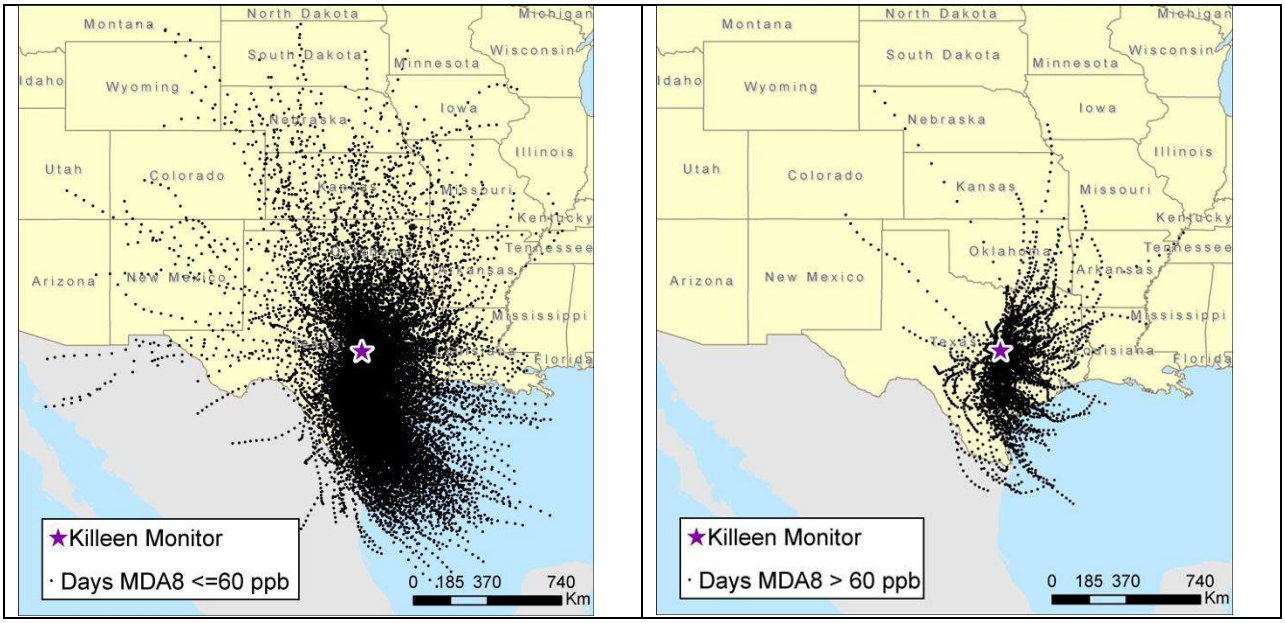


Figure 5-24. 24-hour HYSPLIT backward trajectory plots for ozone season days in 2009-2014 for days with MDA8 less than or equal to 60 ppb (left), and greater than 60 ppb (right).

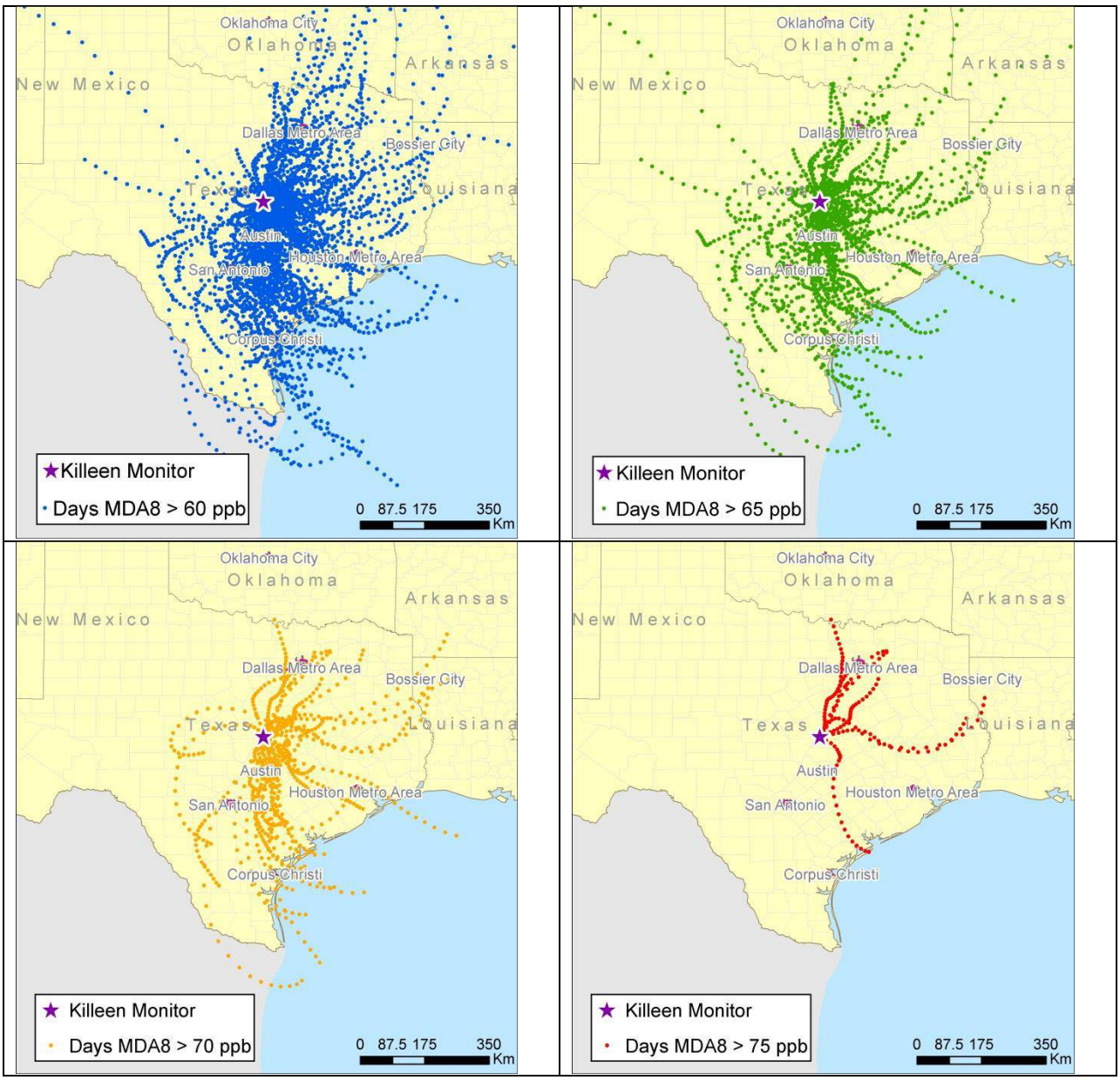


Figure 5-25. 24-hour HYSPLIT backward trajectory plots for ozone season days in 2009-2014 for days with MDA8 ozone > 60 ppb (top left), > 65 ppb (top right), > 70 ppb (bottom left), > 75 ppb (bottom, right).

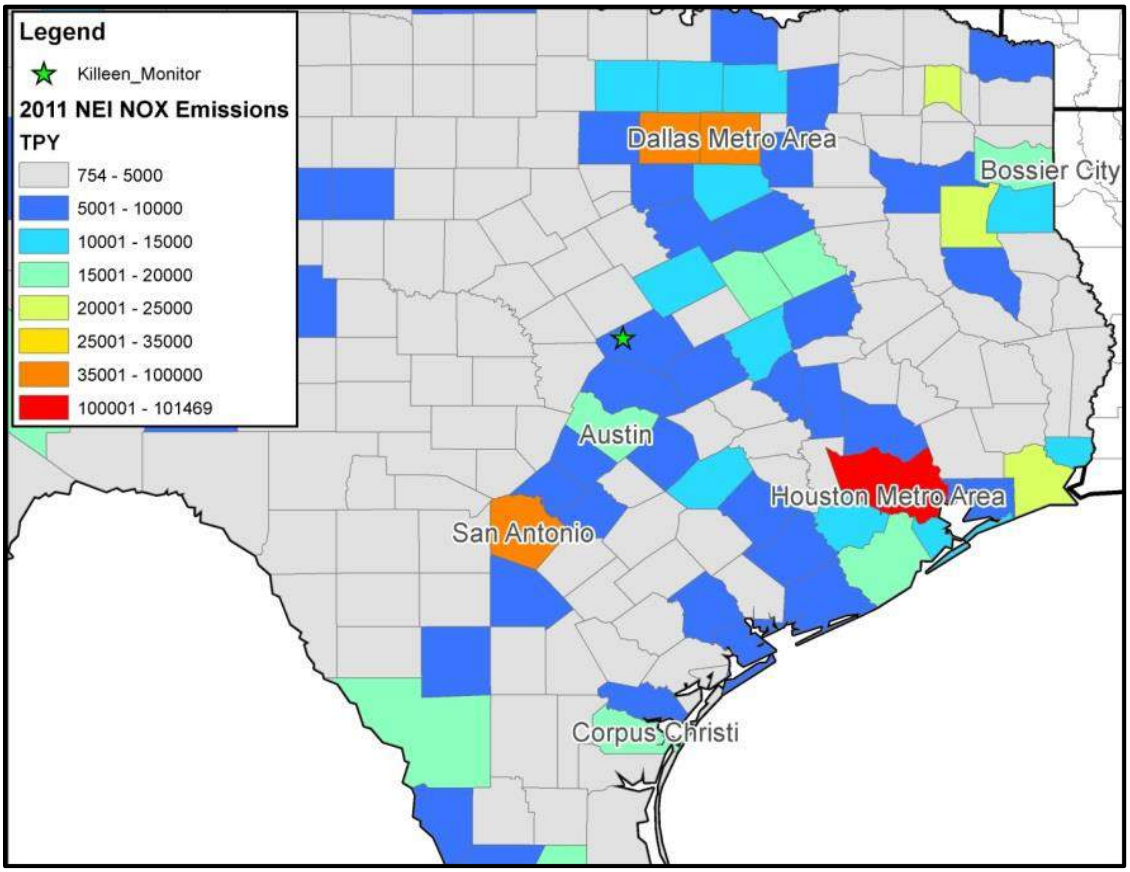


Figure 5-26. Spatial plot of 2011 NEI NOx emissions by county in Texas.

5.5 Meteorological Conditions Associated with High Ozone at Killeen

Meteorological factors are known to play a critical role in ozone formation. Ozone formation is driven by solar ultraviolet radiation through a series of photochemical reactions. Ozone is more likely to form on clear summer days when abundant sunlight reaches the lower atmosphere and daytime temperatures are high. Another local meteorological condition conducive to ozone formation is slow wind speeds since slow winds tend to limit the dispersion of pollutants. Slow or stagnant wind conditions may be due to a surface level high pressure system affecting the region. The location of a monitor in relation to large sources of ozone precursor emissions will be a factor that determines which wind directions may be likely to transport polluted air to a monitor, thus wind direction at some monitors may be an important factor associated with high ozone. This section examines the meteorological conditions associated with high ozone at Killeen. Maximum daily temperature (MDT), average daytime (8 am to 6 pm) wind speeds and resultant average daytime wind directions are compared to MDA8 ozone, for the duration of the monitoring (2009-2014).

Figure 5-27 shows MDT versus MDA8 ozone with the current ozone NAAQS indicated as a dashed red line. There is a general trend showing MDA8 ozone increases with increasing temperatures, but there are also many hot days (i.e. MDT > 80 F) that are not high ozone days. Thus, high temperatures are a necessary but not sufficient condition for high ozone.

In Figure 5-28 the average daytime wind speeds are compared to MDA8 ozone. Days with MDA8 > 75 ppb had wind speeds less than 8 mph with one exception of 10.5 mph. Figure 5-29 presents the resultant wind directions compared to MDA8 ozone. The wind directions most frequently measured at Killeen were between 150 – 200 degrees where the direction is taken as "blowing from". 150 – 200 degrees corresponds to winds blowing from the south-southeast to slightly southwest, but mostly from the south, in agreement with the wind rose and HYSPLIT analyses. The wind directions associated with MDA8 > 75 ppb were winds blowing from 63 to 105 degrees (with one exception) which corresponds to winds blowing from the northeast to east directions.

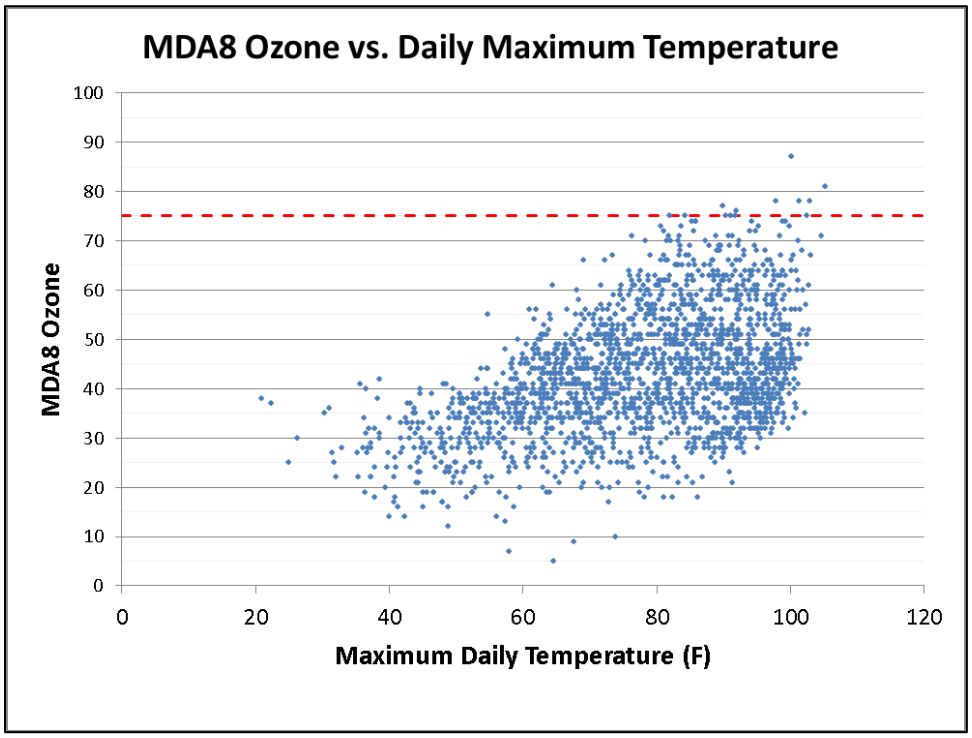


Figure 5-27. Scatter plot of relationship between MDA8 and temperature at Killeen.

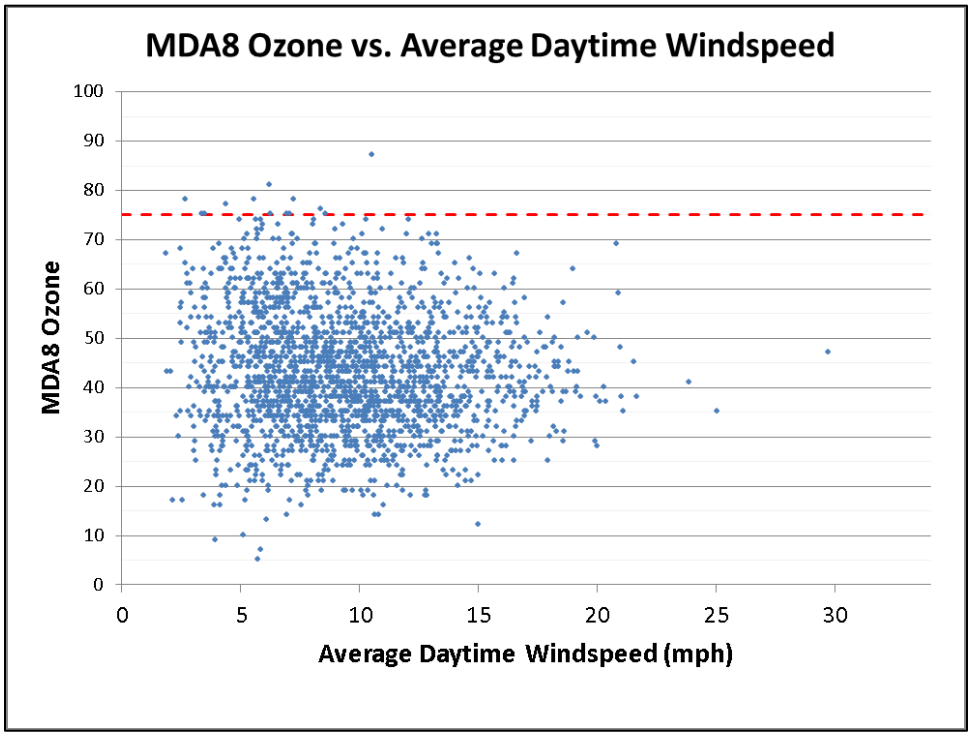


Figure 5-28. Scatter plot of relationship between MDA8 ozone and daytime wind speed at Killeen.

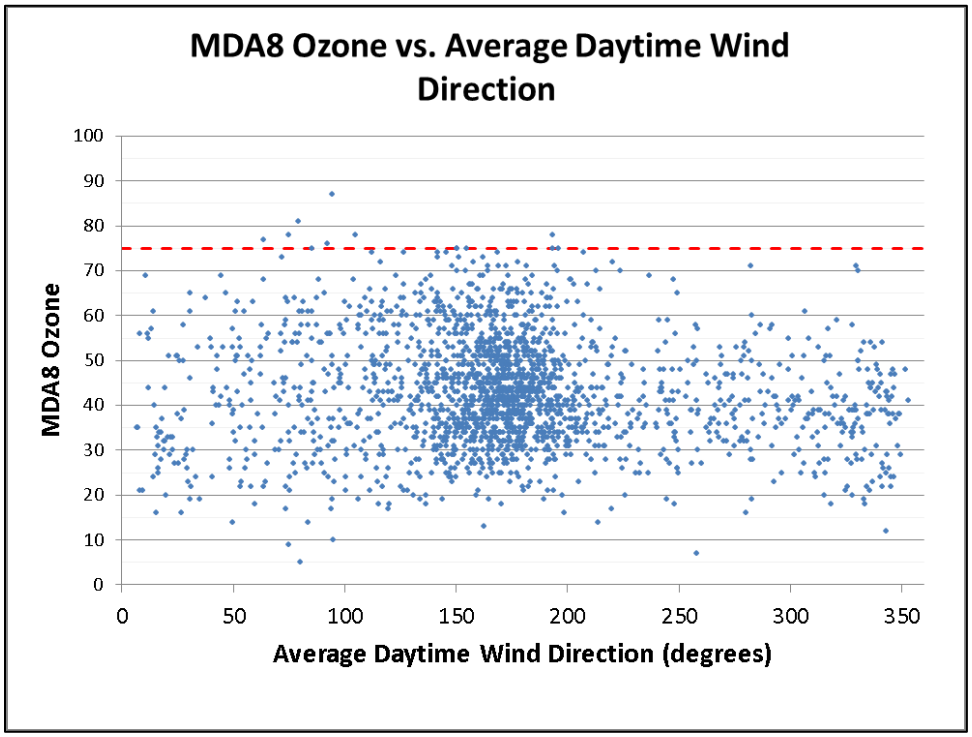


Figure 5-29. Scatter plot of relationship between MDA8 ozone and daytime wind directions at Killeen.

Table 5-6 summarizes the necessary conditions for MDA8 ozone to be greater than 75 ppb as shown in the scatter plots. Since there are only seven days with MDA8 ozone > 75 ppb throughout 2009-2014 at Killeen, another, less restrictive set of conditions is prescribed in order to define a "meteorologically conducive day" and a "meteorologically conducive year". A meteorologically conducive day specifically defined for Killeen satisfies 3 conditions: (1) a MDT condition; (2) a wind speed condition, and; (3) a wind direction condition. The conditions are determined based on the 2009-2014 Killeen data but are less stringent than the necessary conditions for MDA > 75 ppb, and are essentially the conditions necessary for MDA8 > 70 ppb, with a couple of exceptions (i.e. there are a few instances when MDA8 > 70 ppb, but did not meet all the conditions). If the conditions were relaxed to include every day with MDA8 > 70 ppb, then in addition to those few extra MDA8 > 70 ppb days, many more days with MDA8 ≤ 60 ppb would also satisfy the conditions, and therefore the conditions would no longer be most typical of high ozone days. Thus, allowing a couple of exceptions keeps the conditions sufficiently restrictive to focus on the great majority of the high ozone days.

Note that the analysis of meteorological conditions compared to MDA8 ozone at Killeen , particularly in terms of wind speed and direction, does not show as restrictive meteorological conditions as other regions of Texas such as Hood County (Parker et al., 2015). In Hood County, high ozone is nearly exclusively experienced when winds are directly from the northeast, and likely passed over the nearby Dallas-Fort Worth area, whereas for Killeen, a broader range of wind directions is associated with high ozone. The KTF meteorological conditions results are in agreement with the HYSPLIT and wind rose analyses for Killeen , that show that there is not a single dominant emissions source region that influences ozone at Killeen, but rather many possible source regions from north clockwise through south that may be associated with MDA8 ozone > 70 ppb at Killeen.

Table 5-6. Meteorological conditions for high ozone.

Meteorological Variable	Necessary Conditions for MDA8 ozone > 75 ppb	Meteorologically Conducive Conditions used in Analysis
Temperature	> 90 F	> 82
Wind Speed	< 10.5 mph	< 12 mph
Wind Direction Between ("blowing from")	63 and 105 degrees (one exception) (generally northeast to east)	63 and 220 (generally northeast clockwise through south and slightly southwest)

In Figure 5-30, the number of days per year satisfying each of the three conditions separately and all the conditions combined is presented. A day that satisfies all three conditions is defined to be a meteorologically conducive day. The number of meteorologically conducive days is fairly constant from 2010 to 2014 varying only between 115 and 120 days per year. 2014 is the only year that shows a substantially different number of meteorologically conducive days with only 96 days. Since monitoring at Killeen began in June 2009, 2009 cannot be compared with the other years on an equal basis; Figure 5-31, however, reports the number of meteorologically conducive days by year and by month and includes 2009. Taking into account the shorter monitoring data record for 2009, it still appears that 2009 was less meteorologically conducive than 2010 to 2013.

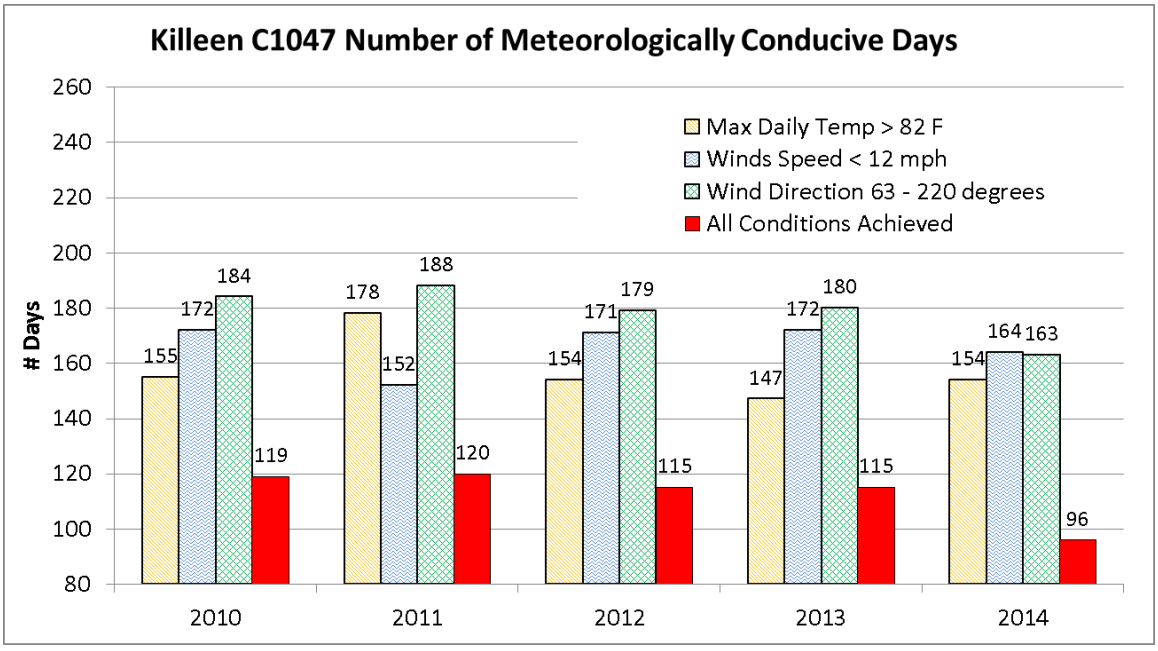


Figure 5-30. Number of meteorologically conducive days per year 2010-2014 at Killeen.

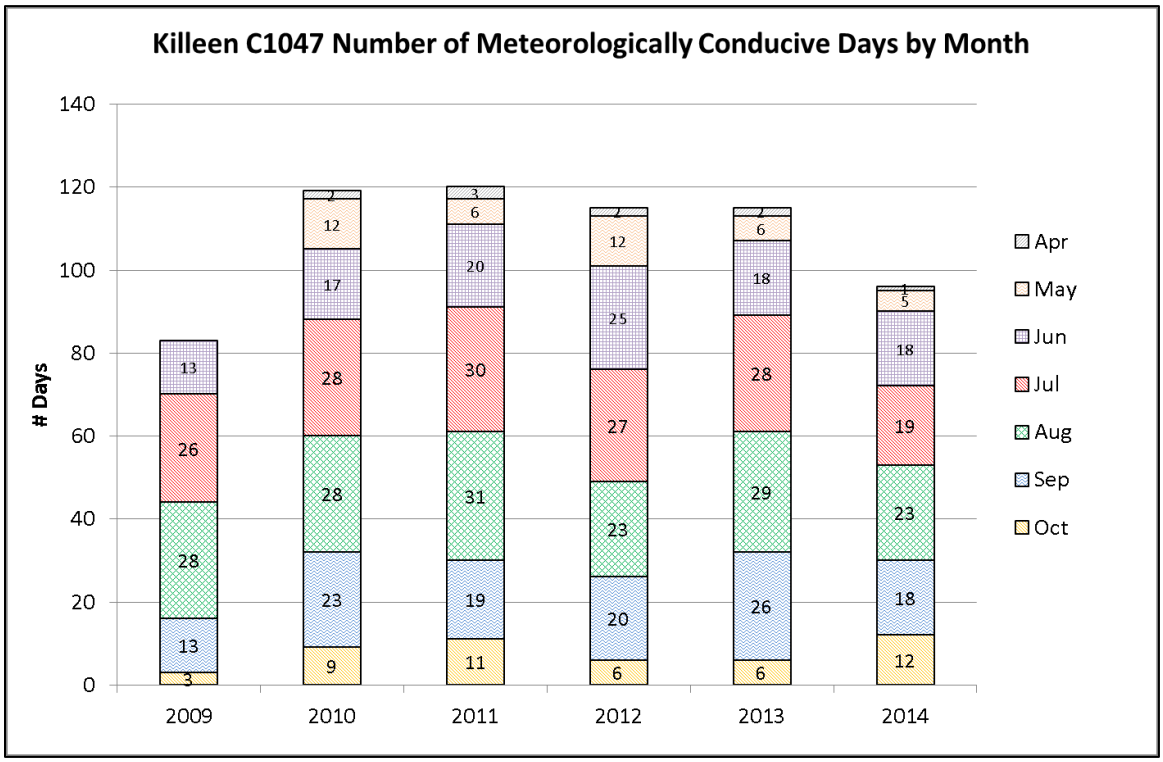


Figure 5-31. Number of meteorologically conducive days per year and per month 2009-2014.

The purpose of evaluating the number of meteorologically conducive days per year is to see if there is a relationship between observed frequency of high ozone days and the frequency of meteorologically conducive days. If so, it may suggest how much year-to-year variability is influenced by meteorological conditions rather than changes in ozone precursor emissions.

Referring back to Figure 5-2 and Figure 5-3 shows that the years with fewest occurrences of MDA8 > 60, 65, 70 and 75 ppb and also the years with the lowest of the annual four highest MDA8 ozone concentrations were 2009 and 2014. These two years correspond to the years with fewest meteorologically conducive days. Therefore, lower ozone in 2009 and 2014 may be attributable in part to weather conditions. The variation in ozone during 2010 – 2013 is not well explained by meteorology using this methodology, implying that this method is either limited or other non-meteorological factors (i.e. emissions changes) were responsible for the variation during those years. For example, Figure 5-31 indicates that July has fewer high ozone days than June, August, and September, but has as many or more meteorologically conducive days as the other months.

Using the more stringent definitions for the criteria to define a meteorologically conducive day (criteria for MDA8>75 ppb; see Table 5-6) results in far fewer days satisfying the meteorologically conducive criteria (55 days versus 648 days over the 6 year period including 2009). However, the correlation between the number of meteorologically conducive days and the number of high ozone days is low for both the MDA8 > 75 ppb (r=0.36) and MDA8 > 70 ppb (r=-0.02) thresholds (Figure 5-32, left panel). Although using the more restrictive wind direction criterion screens out many days with southerly winds, the time series for the number of meteorologically conducive days does not show the July local minimum seen in the time series for the number of high ozone days per month at the 70 ppb and 75 ppb thresholds (Figure 5-32, right panel).

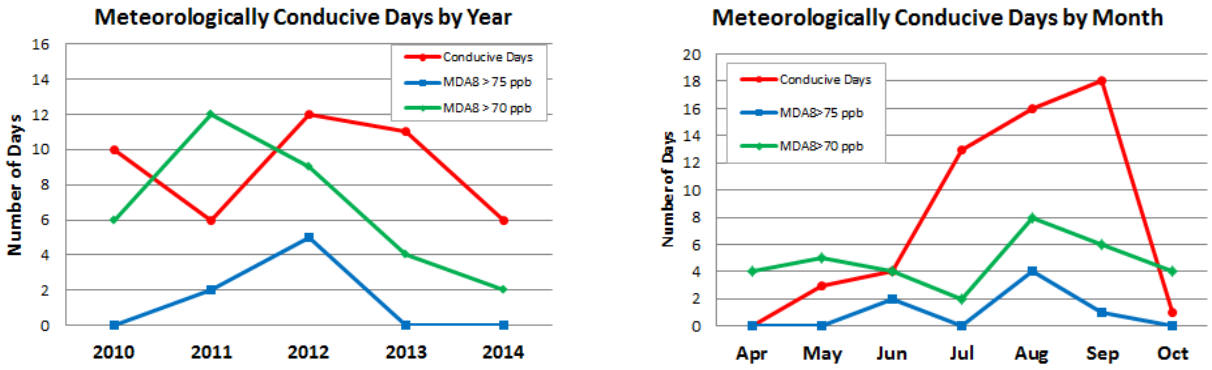


Figure 5-32. Left panel: number of days with MDA8 ozone > 75 ppb and > 70 ppb at the Killeen monitor by year and number of meteorologically conducive days per year 2009-2014 at Killeen using > 75 ppb criteria from Table 5-6. Right panel: number of meteorologically conducive days per month at Killeen during 2010-2014 and number of days in each year with MDA8 ozone > 75 ppb and > 70 ppb at Killeen.

We conclude that there is no obvious correlation between years with high number of meteorologically conducive days and high number of high ozone days when conducive days are defined using the criteria set forth in Table 5-6. This suggests that the criteria shown in Table 5-6 are missing one or more important elements. For example, non-meteorological factors such as wildfire emissions can influence the number of high ozone days in a year. With a longer data record, it might be possible to identify and remove years influenced by a particular factor such as wildfires and reassess the correlation between the number of high ozone days and meteorologically conducive days. Further evaluation of how much year-to-year variability is influenced by meteorological conditions versus changes in ozone precursor emissions is therefore left as an area for future work.

5.6 Killeen High Ozone Day Analysis Summary

Parker et al. (2013) analyzed all days from 2009-2013 when the Killeen monitor measured MDA8 ozone ≥ 75 ppb. Table 5-7 summarizes the findings of Parker et al. (2013). Note that on all high ozone days at Killeen, regional ozone concentrations were high, indicating that high background ozone concentrations are a necessary condition for high ozone at Killeen. In addition, the analysis suggested that there was not a single dominant local or intrastate region contributing to high ozone at Killeen, but rather there are many emissions source regions that may contribute to any particular high ozone day. Figure 5-26 shows that Killeen is located almost equidistant between some of the state's major NOx emitting counties to its northeast and southeast (i.e. DFW and Houston areas). Some other large NOx emitting counties, are located closer to Killeen, namely Limestone, Freestone and Travis County (Austin). In addition, McLennan and Bell County emissions could also potentially influence ozone at Killeen. Based on the Killeen monitor's proximity to various NOx emissions sources, many regions could potentially impact high ozone at Killeen. Photochemical modeling using source apportionment tools can estimate the contribution to high modeled ozone from ozone precursor emissions from various source regions, thus, quantifying individual source region ozone impacts at Killeen. Photochemical modeling was performed for the KTF region and is described in Section 6.

Table 5-7. Summary of Killeen high ozone days analysis 2009–2013. A detailed analysis of each of the days listed below may be found in Parker et al. (2013).

Year	Month	Day	Killeen MDA8 [ppb]	Wind Direction (Blowing from)
2010	August	27	**75**	**SE**
High regional ozone Potential sources: local Killeen , or Waco urban impact, or power plant				
2010	October	08	**75**	**S or SW**
Ozone peak late in the day Potential sources: Austin urban impact or local Killeen				
2011	August	28	**81**	**E**
Regionally high ozone				
2011	August	29	**75**	**S or SE**
Regionally high ozone not as high as previous day Potential sources: Austin urban impact				

Year	Month	Day	Killeen MDA8 [ppb]	Wind Direction (Blowing from)
2011	September	07	**77**	**NNE**
Likely DFW impact, wildfire emissions influenced central Texas				
2011	September	20	**75**	**N (or NW or NE)**
Potential sources: Waco urban impact or local Killeen				
2011	October	15	**75**	**S**
High regional ozone Potential sources: unknown				
2012	June	26	**78**	**stagnant**
High ozone in East TX, Potential sources: local Killeen or Fort Hood				
2012	June	27	**78**	**ESE**
High regional ozone Potential sources: none indicated				
2012	August	10	**87**	**Recirculating**
High regional ozone Potential sources: local Killeen or Fort Hood				
2012	August	11	**78**	**NE**
High regional ozone Potential sources: Waco and/or Temple urban impact, or local Killeen or power plant				
2012	August	20	**76**	**NNE**
High regional ozone Potential sources: local Killeen, or Waco urban impact , or DFW impact				
2013	September	25	**75**	**stagnant**
High regional ozone Potential sources: local Killeen				

5.7 Recommendations

Based on the analyses performed, the following items are recommended:

- NOx and SO_2 monitoring at one or more KTF Area CAMS sites.
  - NOx and SO_2 are not currently monitored at Killeen (CAMS 1047) or Temple Georgia (CAMS 1045) and it is recommended that NOx and SO_2 monitoring be added to those sites. NOx measurements will allow a more in-depth analysis of the effects of on-road mobile sources, as well as discern future KTF Area NOx trends. SO_2 monitoring will allow a better determination of potential sources, particularly coal-fired power plants that may influence high ozone in the KTF Area.

6.0 PHOTOCHEMICAL MODELING

The first step in air quality planning efforts is to understand the nature of the ozone problem. This includes determining the relative importance of local sources of emissions and ozone transported from distant sources as well as which types of local sources make the largest contributions to ozone formation. A photochemical model is a tool for understanding the formation, transport and fate of ozone in an area and is also used in evaluating local emission control strategies. It is similar in many ways to a weather forecast model, and simulates the movement and chemical evolution of pollutants in the atmosphere. Figure 6-1 is a schematic showing a portion of the atmosphere being modeled and some of the physical and chemical process that are simulated. In a photochemical model, the atmosphere is divided into boxes and the model solves for the concentration of ozone, NOx, VOCs and other species of interest in each box throughout the modeled episode. The concentration of chemical species in each box changes with time due to the effects of physical and chemical process such as emissions, photochemical production, transport into the box from neighboring boxes, loss by deposition onto the surface or by uptake into plants, etc.

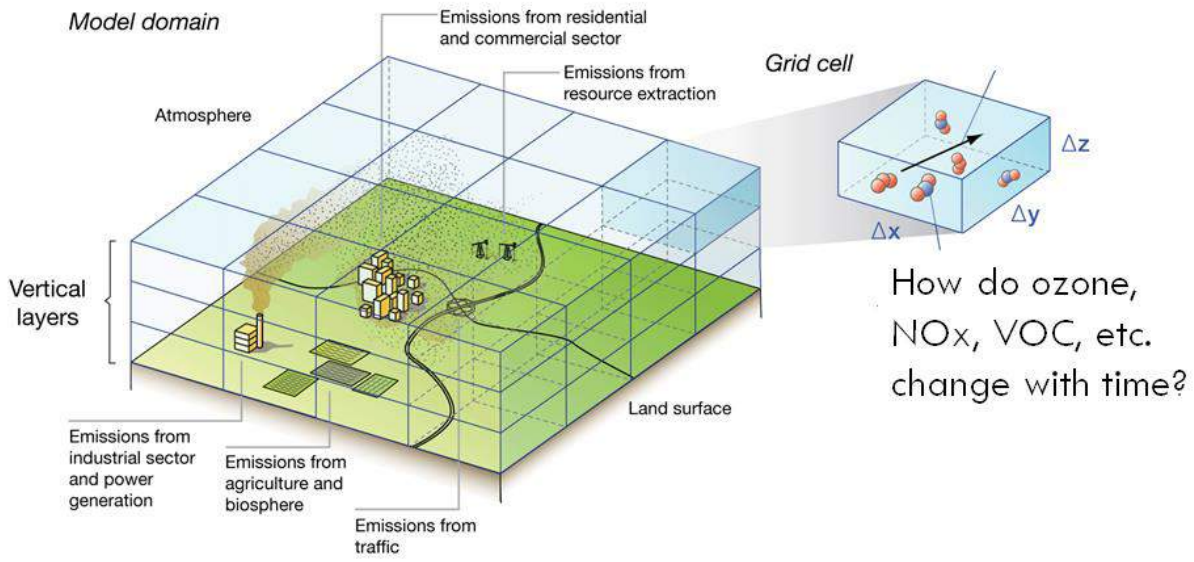


Figure 6-1. Photochemical model schematic showing a portion of the modeling domain. Figure from AWMA Environmental Manager magazine July 2012 issue on AQMEII by Douw Steyn, Peter Builtjes , Martijn Schaap and Greg Yarwood.

In this Section, we quantify sources of ozone contributions to KTF ambient ozone concentrations using a June 2012 photochemical model developed by the TCEQ for modeling by the Texas Near Non-Attainment regions (NNAs).

We analyze results from the photochemical model for several receptors in the KTF region to quantify sources of ozone contributions to KTF during the elevated ozone period in June 2012. We focus our ozone model performance evaluation for June 2012 on the Killeen monitor, the

only active CAMS site in the KTF region during this period. Our analysis of source apportionment results need not be limited to sites with monitoring during the modeled period, so we include receptor locations at the Temple Georgia monitoring site along with several other "virtual monitors" in the other counties in the KTF region. These "virtual monitors" do not correspond to actual CAMS ozone monitoring sites, but are receptor locations that are treated in the same way as actual CAMS monitors by the ozone model. Through the use of virtual monitors, we can use the ozone model to assess sources/regions contributing to ozone in the unmonitored regions of the KTF Area. We placed virtual monitors in the largest population centers in each county of the KTF Area to determine whether ozone levels and source apportionment varied significantly from location to location within the 7-county area.

In Section 6, we describe the configuration of the June 2012 photochemical model used for ozone source apportionment analysis and evaluate the model's performance in simulating observed ozone at the Killeen monitor in June 2012. We present a source apportionment analysis of ozone contributions at various KTF Area locations to quantify impacts of KTF emissions sources on ambient ozone concentrations at these receptors. Finally, we summarize findings of the photochemical modeling and make recommendations for further work.

6.1 June 2012 Ozone Model

In this Section, we discuss development of the meteorological database and configuration of the photochemical grid model for modeling the KTF region during the period June 1-30, 2012. In Section 6.1.1, we discuss the meteorological model configuration. In Section 6.1.2 we describe CAMx photochemical model configuration and in Section 6.1.3 we describe the ozone model performance evaluation against observed ground level ozone at the Killeen monitor.

A June 2012 modeling database was prepared by the TCEQ for use by the Texas NNAs. The TCEQ prepared meteorological inputs for CAMx, developed emission inventories and made available other inputs such as model boundary conditions. These model inputs are described below. The photochemical grid model used for this application was the Comprehensive Air Quality Model with Extensions (CAMx; Ramboll Environ, 2015). CAMx is a three-dimensional chemical-transport photochemical grid model and is used for ozone air-quality planning in Texas

6.1.1 Meteorological Data

CAMx requires meteorological input data for the parameters shown in Table 6-1. For the June 2012 episode, the TCEQ developed meteorological input data for CAMx using the Weather Research and Forecast (WRF) meteorological model version 3.6.1 (Skamarock et al., 2005) and then processed WRF outputs using the WRFCAMx preprocessor to generate model-ready meteorological files containing each field in Table 6-1.

Table 6-1. CAMx meteorological input data requirements.

Input Parameter	Description
Layer interface height (m)	3-D gridded time-varying layer heights for the start and end of each hour
Winds (m/s)	3-D gridded wind vectors (u,v) for the start and end of each hour
Temperature (K)	3-D gridded temperature and 2-D gridded surface temperature for the start and end of each hour
Pressure (mb)	3-D gridded pressure for the start and end of each hour
Vertical Diffusivity (m^2/s)	3-D gridded vertical exchange coefficients for each hour
Water Vapor (ppm)	3-D gridded water vapor mixing ratio for each hour
Clouds and Rainfall (g/m^3)	3-D gridded cloud and rain liquid water content for each hour

6.1.1.1 WRF Model Configuration

6.1.1.1.1 Modeling Domain

WRF coarse and nested grids defined by the TCEQ are shown in Figure 6-2. Modeling domains are defined on a Lambert Conformal Conic (LCC) map projection identical to that used in the Regional Planning Organization (RPO) modeling[27]. The RPO projection is defined to have true latitudes of 33°N and 45°N and central latitude and longitude point (97°W, 40°N). The 36 km WRF modeling domain encompasses the continental U.S. and parts of Canada and Mexico. The 12 km grid includes Texas and adjacent states and the 4 km grid is centered on East Texas. WRF 36, 12 and 4 km grids are slightly larger than the corresponding CAMx grids to remove any artifacts (i.e., numerical noise) that can arise in WRF adjacent to fine grid boundaries.

[27] http://www.epa.gov/visibility/regional.html

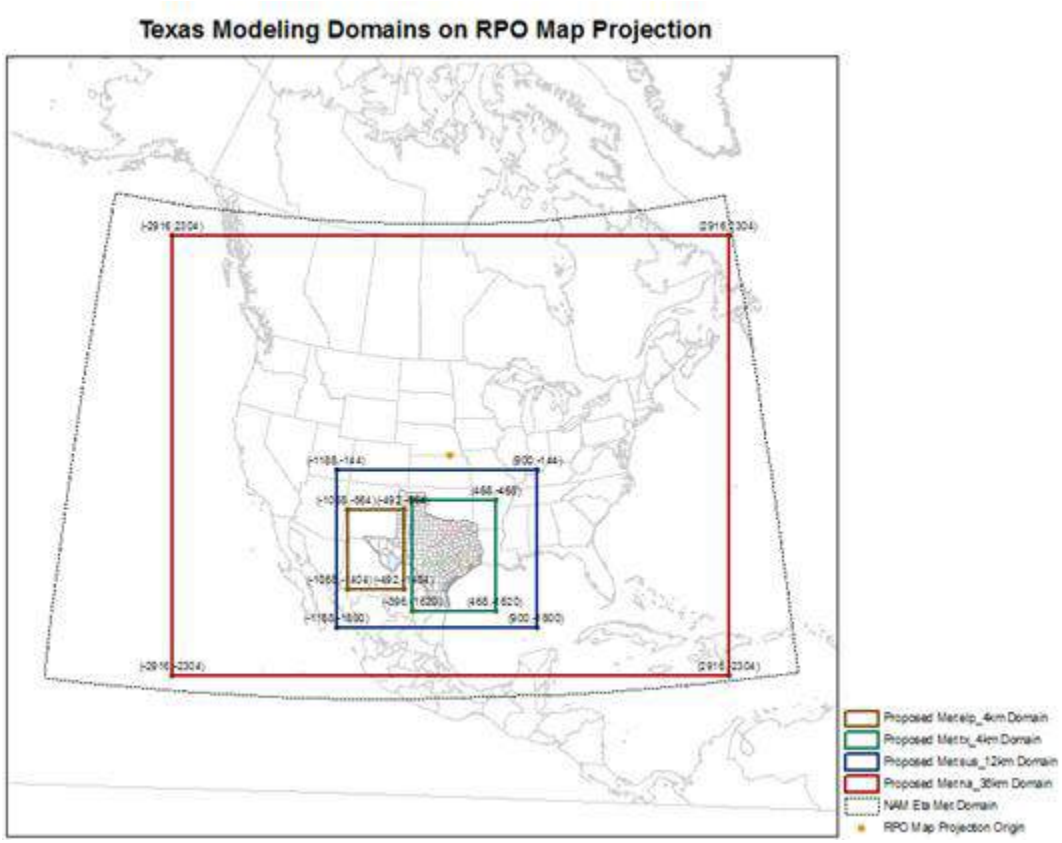


Figure 6-2. TCEQ's WRF modeling 36/12/4 km grid system for regional scale modeling on the RPO projection. Figure from Breitenbach (2010).

6.1.1.1.2 Vertical Layer Structure

EPA's current guidance on applying models for 8-hour ozone [28] (EPA, 2014a) includes the following information on vertical layer structure:

- There is no current recommended number of vertical layers, however EPA notes that recent applications have used 14-35 vertical layers;
- The surface layer should be no thicker than 40 m;
- Excessively thick layers within the PBL are to be avoided; and
- The top of the modeling domain should be set at the 100 millibars (mb; ~16,000 meters [m]) atmospheric pressure level for modeled periods that include meteorological conditions that are not dominated by synoptic high pressure systems and are not free of clouds and precipitation.

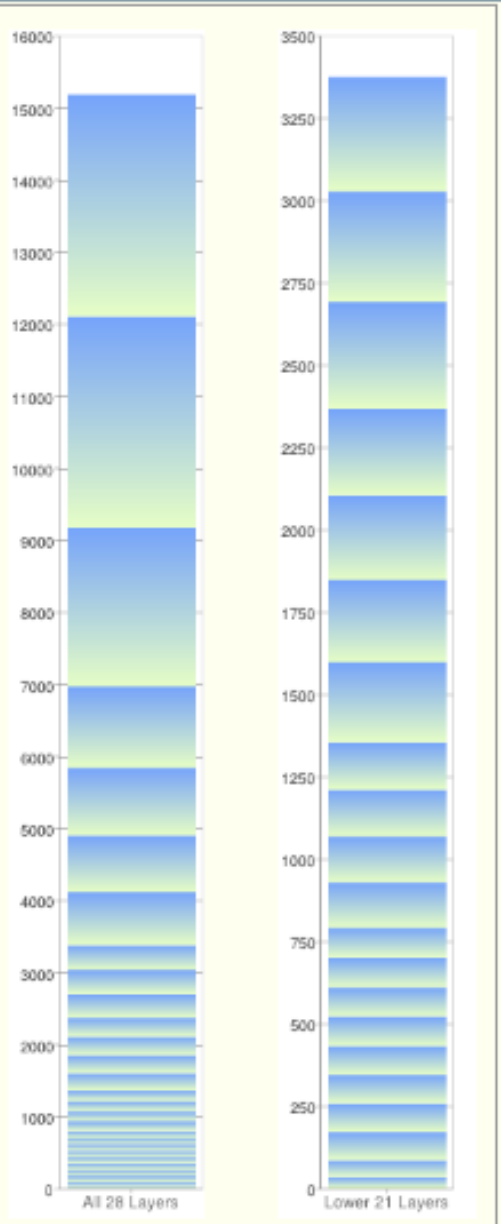
[28] http://www.epa.gov/ttn/scram/guidance/guide/Draft_O3-PM-RH_Modeling_Guidance-2014.pdf

The TCEQ modeling system's vertical structure satisfies all of the above criteria. Table 6-2 shows layer heights and centers for WRF and CAMx modeling.

Table 6-2. Rider 8 WRF and CAMx model layer structure. TCEQ figure from http://www.tceq.texas.gov/airquality/airmod/rider8/modeling/domain.

Vertical Layer Structure

Corresponding WRF Layer	Layer Top (m AGL)	CAMx Layer	Layer Center (m AGL)	Thickness (m)
38	15179.1	28	13637.9	3082.5
36	12096.6	27	10631.6	2930.0
32	9166.6	26	8063.8	2205.7
29	6960.9	25	6398.4	1125.0
27	5835.9	24	5367.0	937.9
25	4898.0	23	4502.2	791.6
23	4106.4	22	3739.9	733.0
21	3373.5	21	3199.9	347.2
20	3026.3	20	2858.3	335.9
19	2690.4	19	2528.3	324.3
18	2366.1	18	2234.7	262.8
17	2103.3	17	1975.2	256.2
16	1847.2	16	1722.2	249.9
15	1597.3	15	1475.3	243.9
14	1353.4	14	1281.6	143.6
13	1209.8	13	1139.0	141.6
12	1068.2	12	998.3	139.7
11	928.5	11	859.5	137.8
10	790.6	10	745.2	90.9
9	699.7	9	654.7	90.1
8	609.7	8	565.0	89.3
7	520.3	7	476.1	88.5
6	431.8	6	387.9	87.8
5	344.0	5	300.5	87.1
4	256.9	4	213.8	86.3
3	170.6	3	127.8	85.6
2	85.0	2	59.4	51.0
1	33.9	1	17.0	33.9



AGL - Above Ground Level.

6.1.1.1.3 Column Physics and Data Assimilation

Model physics options for the WRF simulation are shown in Table 6-3.

Table 6-3. Physics Parameterizations used in the TCEQ WRF simulation.

Process	Physics Parameterization	
	36/12 km Grid	4 km Grid
Cumulus Parameterization	Kain-Fritsch	None
Radiation (LW/SW)	RRTM/Dudhia	RRTM/Dudhia
Cloud Microphysics	WSM5	WSM6
PBL/Surface Physics	YSU/PX	YSU/PX

6.1.1.1.4 WRFCAMx Configuration

The TCEQ used the WRFCAMx v4.2 preprocessor to convert raw WRF output files into model-ready input files formatted for CAMx. WRFCAMx was used to calculate vertical turbulent exchange coefficients (Kv) which are derived from meteorological data supplied to CAMx by the WRF meteorological model. The CMAQ Kv method was used. The CAMx pre-processor KVPATCH was then used to adjust Kv to improve turbulent coupling between the surface and lower boundary layer. The Kv 100 patch was applied to Kv calculated within WRFCAMx. In the Kv 100 patch the minimum Kv for all layers within the lowest 100 m (defined to be the stable boundary layer) is set to the maximum Kv value found within the lowest 100 m.

6.1.2 CAMx Model Configuration

The TCEQ provided information on CAMx air quality modeling domains and all additional inputs required to run the model. These are described below.

6.1.2.1 CAMx Modeling Domain

For the June 2012 episode, the modeling domain for WRF meteorological modeling and the domain for the CAMx ozone model must both be specified. There is necessarily a close relationship between CAMx and WRF grids to ensure that meteorological information is transferred accurately from WRF to CAMx. To minimize interpolation of meteorological variables from WRF to CAMx and the resulting potential for disruption of mass consistency, CAMx used the same coordinate system as WRF. The TCEQ defined CAMx modeling grids to use the same LCC projection as the WRF modeling.

EPA's guidance on applying models for 8-hour ozone (EPA, 2014a) states that the most important factors that determine the horizontal extent of the domain are the nature of the ozone problem and the spatial scale of emissions which affect the region of interest. The overall strategy in defining a nested modeling grid system is that a fine grid provides higher resolution in the area of interest while a coarse grid provides computational efficiency over a larger modeling region. The TCEQ nested grid air quality modeling system for the June 2012 episode is shown in Figure 6-3. In accordance with EPA (2014a) guidance, the outer 36 km domain shown in black in Figure 6-3 was designed to be large enough to encompass all important upwind sources of emissions and to allow use of clean or relatively clean boundary conditions. Backward trajectory analyses performed by the TCEQ have suggested that air mass transport

from the Ohio Valley/Midwest to Texas occurs frequently so the 36 km modeling domain is consistent with EPA's guidance that all major upwind source areas that influence the downwind area are included in the modeling domain (EPA, 2014a).

The 12 km grid (shown in blue in Figure 6-3) includes all areas in eastern Texas that are conducting ozone modeling so that a consistent 12 km grid can be used in all studies. In addition the 12 km grid includes a substantial area that would typically be upwind of Texas during an ozone episode with easterly or northeasterly winds. This is important to accurately represent any influence of ozone transport since ozone formation is modeled more accurately by a 12 km grid than a 36 km grid. The intention is to accurately model potential transport of ozone from areas at a distance upwind from Texas of about the breadth of one state.

The TCEQ specified a set of 3 nested modeling grids (36/12/4 km) designed to be suitable for use by all NNAs. The TCEQ supplied emissions and meteorological inputs for the June 2012 episode on these grids.

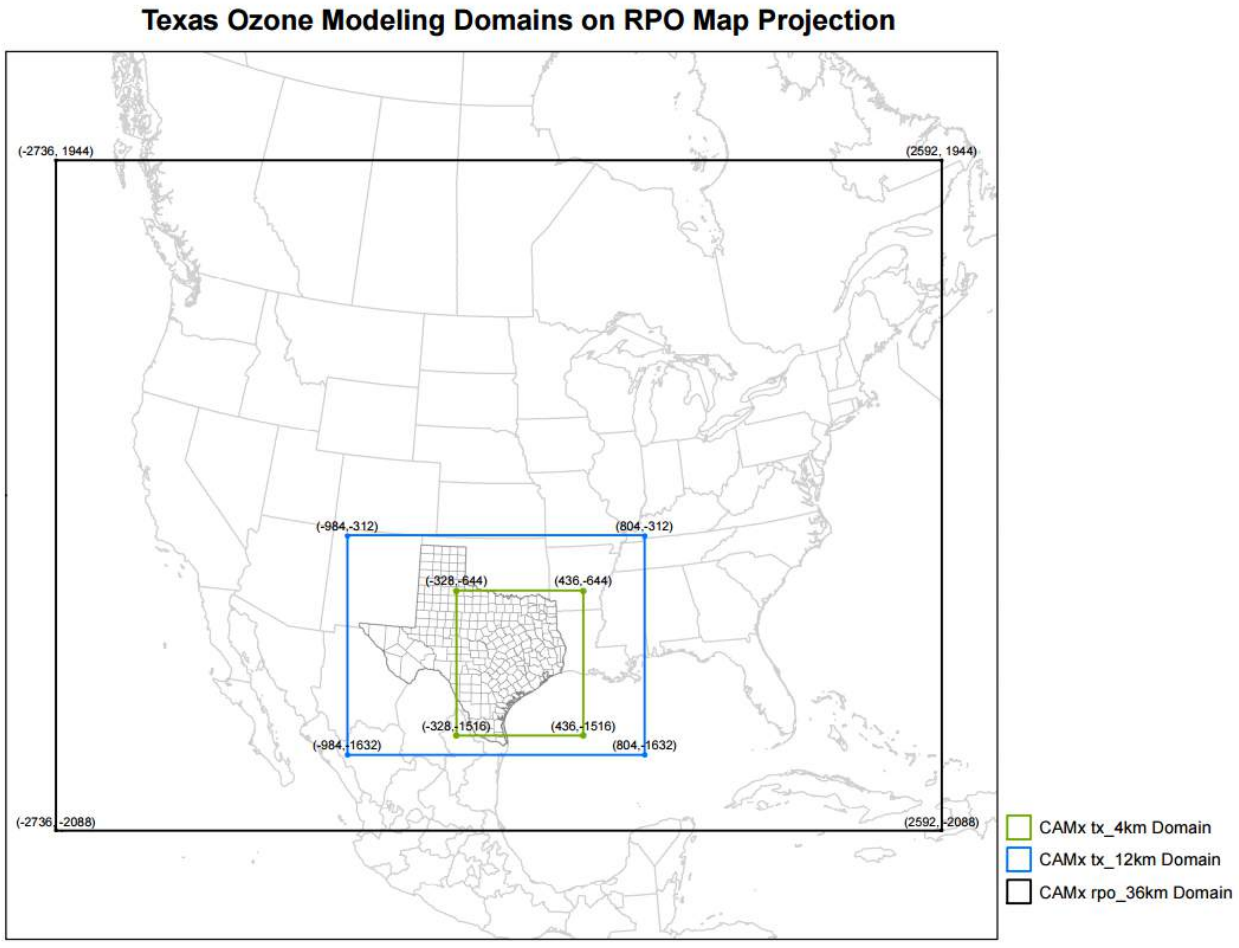


Figure 6-3. TCEQ 36/12/4 km CAMx nested modeling grids for the Texas ozone modeling of June 2012.

The TCEQ's 4 km grid (shown in green in Figure 6-3) encompasses the KTF region as well as the Eagle Ford Shale geological formation and nearby metropolitan areas including Houston-Galveston-Brazoria (HGB), Austin and Waco. Due to the potential for significant ozone impacts from emissions sources in surrounding Texas regions, it is important to use high resolution 4 km modeling to accurately simulate local and regional ozone production and transport into the KTF region.

6.1.2.2 Other Inputs

A global chemistry-transport model (GEOS-Chem; Bey et al., 2001) was run to provide boundary conditions for the 36 km grid in the June 2012 model, and the TCEQ provided these boundary conditions to Ramboll Environ. Global- and regional-scale models typically have too much ozone over the ocean. Several theories have been proposed for why this overabundance of ozone exists (e.g. McFiggans et al., 2000 and Read et al., 2008), but since no scientific consensus currently exists, we used an ad hoc adjustment to the 36 km grid boundary conditions to minimize the effect of global model bias on the CAMx simulation. We performed a flat 10 ppb ozone reduction and applied a set of caps to ozone precursors and other key species (Table 6-4) in all 36 km grid cells located over the Gulf of Mexico and Atlantic Ocean in order to reduce potential high bias in ozone transported onshore.

Table 6-4. Maximum concentration limits for ozone precursors and other key species applied to the 36 km boundary condition grid cells across the Gulf of Mexico, the Caribbean Sea, and the Atlantic Ocean south of Cape Hatteras.

Species	Description	Max. Concentration (ppb)
NO2	Nitrogen dioxide	0.05
CO	Carbon monoxide	150.0
N2O5	Dinitrogen pentoxide	0.001
HNO3	Nitric acid	0.25
PNA	Peroxynitric acid	0.001
H2O2	Hydrogen peroxide	0.5
NTR	Organic nitrates	0.01
FORM	Formaldehyde	0.25
ALD2	Acetaldehyde	0.05
ALDX	Propionaldehyde and higher aldehydes	0.02
PAR	Paraffin carbon bond (C-C)	1.0
OLE	Terminal olefin carbon bond (R-C=C)	0.01
ETHA	Ethane	1.0
MEPX	Methylhydroperoxide	0.1
PAN	Peroxyacetyl Nitrate	0.01
PANX	C3 and higher peroxyacyl nitrate	0.001
INTR	Organic nitrates from ISO2 reaction with NO	0.001
ISOP	Isoprene	0.1

Species	Description	Max. Concentration (ppb)
ISPD	Isoprene product (lumped methacrolein, methyl vinyl ketone, etc.)	0.1
TERP	Monoterpenes	0.05
ISP	Isoprene (SOA chemistry)	0.1
TRP	Monoterpenes (SOA chemistry)	0.05
TOL	Toluene and other monoalkyl aromatics	0.02
XYL	Xylene and other polyalkyl aromatics	0.01
SO2	Sulfur dioxide	0.1
PRPA	Propane	0.5
ACET	Acetone	0.25
KET	Ketone carbon bond (C=O)	0.05
BENZ	Benzene	0.1

The TCEQ also provided other required inputs to NNAs such as photolysis rates, chemistry parameters, land use input files and total ozone column files. These were obtained from the TCEQ's website[29].

6.1.3 Model Performance Evaluation

The performance of the CAMx run in simulating surface layer ozone was evaluated at CAMS sites within the 4 km modeling grid. The goal of the evaluation was to determine how well CAMx was able to reproduce observed ozone concentrations during June 2012.

Consistent with EPA Modeling Guidance (EPA, 2014), we used multiple statistical metrics in the model performance evaluation. We evaluated the root mean square error (RMSE), normalized mean bias (NMB), and normalized mean error (NME).

The statistical metrics are defined as follows:

- Normalized Mean Bias (NMB)

$$NMB = \frac{\sum_{i=1}^{N}(P_i - O_i)}{\sum_{i=1}^{N} O_i}$$

where P_i and O_i are the predicted and observed values (O_i,P_i) in a data pair and N is the number of observed/modeled data pairs. NMB shows whether a modeled quantity such as ozone is under- or overpredicted on average compared to observations.

[29] http://www.tceq.texas.gov/airquality/airmod/data/tx2012

- Normalized Mean Error (NME)

$$NME = \frac{\sum_{i=1}^{N}|P_i - O_i|}{\sum_{i=1}^{N} O_i}$$

NME is similar to NMB, but calculates the absolute value of the difference between the observed and modeled values. It is useful to compare the magnitudes of the NMB and NME statistics together to determine the nature of the biases. For example, if the NMB equals +10% and the NME equals 10%, then the model error is completely explained by positive biases.

- Root Mean Squared Error (RMSE)

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(P_i - O_i)^2}{N}}$$

RMSE is a general purpose statistical metric used to measure model performance in meteorological and air quality studies. Because the difference between the observed and modeled values is squared, occasional large errors are penalized more than with other metrics.

We evaluated CAMx surface layer ozone performance for all monitors in the Texas 4 km grid that were active in June 2012. We found that at sites throughout East Texas, the model has an overall high bias, but replicates the variability of ground level ozone reasonably well (Appendix D). Here, we focus on model performance at the Killeen CAMS monitor. The Temple Georgia monitor was not active in 2012, so the Killeen monitor is the only site in the KTF Area available for model performance evaluation.

6.1.3.1 June 2012 Ozone Model Performance at Killeen Monitor

For the Killeen monitor, we compare modeled and observed ozone. Figure 6-4 shows measured and modeled time series for 1-hour ozone (upper panel), along with NMB, NME and RMSE for 8-hour ozone (lower three panels from top to bottom, respectively) during the June 2012 period at the Killeen monitor.

Figure 6-4 shows that at Killeen, the model has an overall high bias, but has a low bias during periods when observed ozone exceeds 70 ppb. Measurements of maximum daily average 1-hour (MDA1) ozone exceeded 70 ppb at the Killeen monitor on 5 days: June 1, 22, and 25-27. On these five days, CAMx under-predicted the MDA1 ozone by at least 6 ppb. On June 26, when the observed MDA1 at Killeen was 91 ppb, CAMx predicted a value of 75 ppb. Peak 1-hour ozone on June 26 occurred at 10 am. The relatively early timing of the peak suggests the influence of local sources in addition to the influence of high regional background ozone (Parker et al., 2013). Analysis of back trajectories ending at the Killeen monitor on June 26 by Parker et al. (2013) suggests stagnant and recirculating winds with a westerly component near the time

of peak 1-hour ozone at the Killeen monitor. We note that local emissions, especially for the Fort Hood area, are uncertain and likely to be underestimated (Grant et al., 2015). These underestimated emissions may partly explain the reason for the low biases. Wind errors could also contribute to ozone under-prediction. Determining the exact causes for the ozone under-prediction on this high ozone day at Killeen requires further diagnosis.

The daily 8-hour NMB for June 1 is -14%, which is the same magnitude as the NME. This suggests that the error is completely explained by the negative bias. In contrast, the NMB statistics for June 22, 25, 26 and 27 (3%, 2%, -6% and -9%, respectively) comprise only a fraction of the NME (7%, 10%, 12% and 13%), which suggests that a mixture of negative and positive biases exist on these days. Examination of the hourly ozone time series reveals over-predictions of overnight/early morning ozone minima on all four of these days.

Another feature shown in observed hourly ozone time series in Figure 6-4 is the frequent occurrence of evening peaks in ozone concentration. In the evening, photochemical production of ozone falls off with diminishing sunlight and the timing of peak ozone late in the day can indicate the arrival of a plume of ozone transported from outside the local area. Examples of this phenomena occur on June (6 pm peak), June 22 (5 pm peak), and June 27 (6 pm peak). CAMx did not capture the sudden ozone decrease in the afternoon and evening of June 8, which caused a large over-prediction (+23 ppb) at the time of peak transport at midnight. A similar overprediction occurred on June 7.

We recommend that a complete WRF meteorological performance evaluation be performed at the Killeen monitor. The region is greatly influenced by transported ozone, so wind speed and wind direction errors could contribute to ozone biases. Additionally, a previous analysis of the June 2012 WRF meteorology used in this modeling application showed that underestimates of clouds leads to overestimated solar radiation at CAMS monitoring sites (Johnson et al., 2014). Lack of cloud cover in the meteorological model can lead to peak ozone over-predictions, which may explain positive ozone biases found on June 19-20 in the hourly time series in Figure 6-4.

Overall, our evaluation of photochemical model performance at the Killeen monitor shows that the model captures much of the observed ozone variability but has an overall high bias and negative biases on days when ozone exceeds 70 ppb. These biases may result from sources that are not well-characterized in the local KTF emissions inventory and/or errors in modeled winds. While these errors could affect the details of the ozone source apportionment analysis presented in Section 4, it should not affect the qualitative nature of the results.

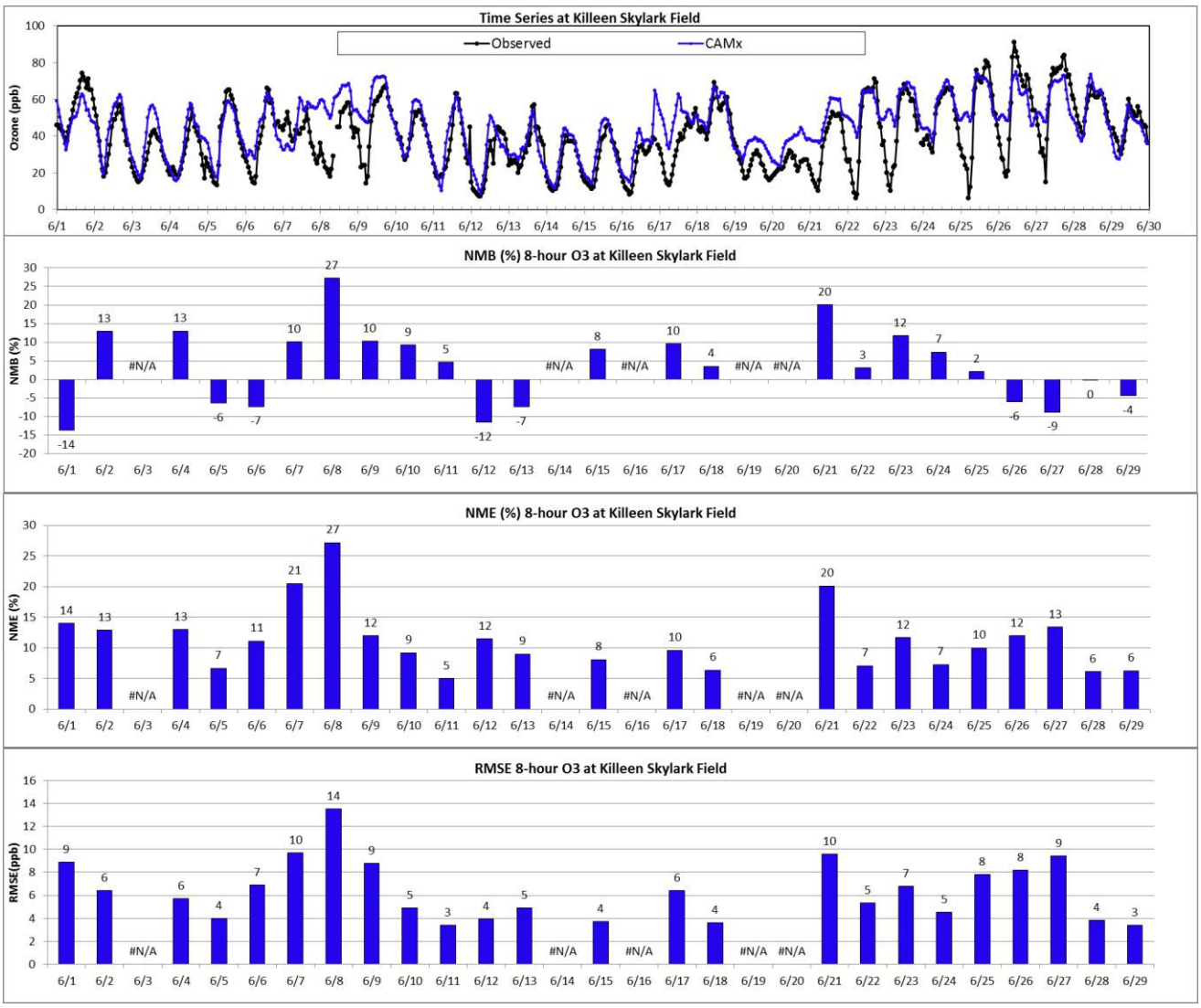


Figure 6-4. Top panel: observed 1-hour ozone (black) at the Killeen monitor versus modeled 1-hour average surface layer ozone during the June 1-29, 2012 period. Lower three panels: normalized mean bias (NMB), normalized mean error (NME) and root mean squared error (RMSE) for the Killeen monitor.

6.2 2012 Ozone Source Apportionment Modeling

The CAMx model's source apportionment capability was used to estimate the relative importance of transport versus local emissions in causing MDA8 ozone to exceed 75 ppb in the KTF region. Source apportionment was also used to estimate which categories of local emissions play an important role in the contribution of local emissions to ozone in the KTF region. The CAMx source apportionment tool used in this analysis is described in Section 6.2.1 and the results of the source apportionment analysis are given in Section 6.2.2.

6.2.1 Description of the CAMx APCA Source Apportionment Tool

The CAMx Anthropogenic Precursor Culpability Assessment (APCA) tool uses multiple tracer species to track the fate of ozone precursor emissions (VOC and NOx) and ozone formation caused by these emissions within a simulation. Tracers operate as spectators to the normal CAMx calculations so that underlying CAMx-predicted relationships between emission groups (sources) and ozone concentrations at specific locations (receptors) are not perturbed. Tracers of this type are conventionally referred to as "passive tracers"; however, it is important to realize that tracers in the APCA tool track effects of chemical reaction, transport, diffusion, emissions and deposition within CAMx. In recognition of this, they are described as "ozone reaction tracers." Ozone reaction tracers allow ozone formation from multiple "source groupings" to be tracked simultaneously within a single simulation. A source grouping can be defined in terms of geographical area and/or emission category. So that all sources of ozone precursors are accounted for, CAMx boundary conditions and initial conditions are always tracked as separate source groupings. This allows an assessment of the role of transported ozone and precursors in contributing to ozone episodes within the KTF region.

The methodology is designed so that all ozone and precursor concentrations are attributed among the selected source groupings at all times. Thus, for all receptor locations and times, ozone (or ozone precursor concentrations) predicted by CAMx is attributed among the source groupings. The methodology also estimates fractions of ozone arriving at the receptor that were formed en-route under VOC or NOx-limited conditions. This information suggests whether ozone concentrations at the receptor may be responsive to reductions in VOC and NOx precursor emissions and can guide development of additional sensitivity analyses.

APCA differs from the standard CAMx Ozone Source Apportionment Tool (OSAT) in recognizing that certain emission groups are not controllable (e.g., biogenic emissions) and that apportioning ozone production to these groups does not provide information that is relevant to development of control strategies. To address this, in situations where OSAT would attribute ozone production to non-controllable (i.e., biogenic) emissions, APCA re-allocates that ozone production to the controllable portion of precursors that participate in ozone formation with the non-controllable precursor. For example, when ozone formation is due to biogenic VOC and anthropogenic NOx under VOC-limited conditions (a situation in which OSAT would attribute ozone production to biogenic VOC), APCA re-directs that attribution to the anthropogenic NOx precursors present. Use of APCA instead of OSAT results in more ozone formation attributed to anthropogenic NOx sources and less ozone formation attributed to biogenic VOC sources but generally does not change the partitioning of ozone attributed to local sources and the transported background for a given receptor.

6.2.2 APCA Results

In this section we describe the following: the local versus transported contribution (Section 6.2.2.1), comparison of regions influencing ozone at the Killeen and Temple Georgia monitors (Section 6.2.2.2), comparison of the importance of anthropogenic NOx and VOC emissions in contributing to high ozone in the KTF Area (Section 6.2.2.3), and the contribution of KTF emissions to ozone at monitors outside the 7-county region (Section 6.2.2.4). Figure 6-5 shows

the source region map used in the APCA analysis. The map shows the outline of the CAMx 12 km boundary in red and 4 km boundary in blue. All areas outside the 12 km grid that are not part of Mexico are defined to be part of the "Other" source region. For this analysis, we combine the Mexico and Other regions into a single "non-Texas" region.

The contribution to KTF ozone from local emissions sources is reckoned using the source region boundary shown below that encompasses the 7-county KTF Area, which is referred to as the CTCOG region in the analysis that follows. The Austin and San Antonio NNAs are broken out into separate source regions as the CAPital region Council of Governments (CPCOG) and Alamo Area Council of Governments (AACG), respectively, as are the Houston-Galveston-Brazoria (HGB), Beaumont-Port Arthur (BPA) and Dallas-Fort Worth (DFW) non-attainment areas. The remaining areas of East Texas are grouped into source regions as shown in Figure 6-5.

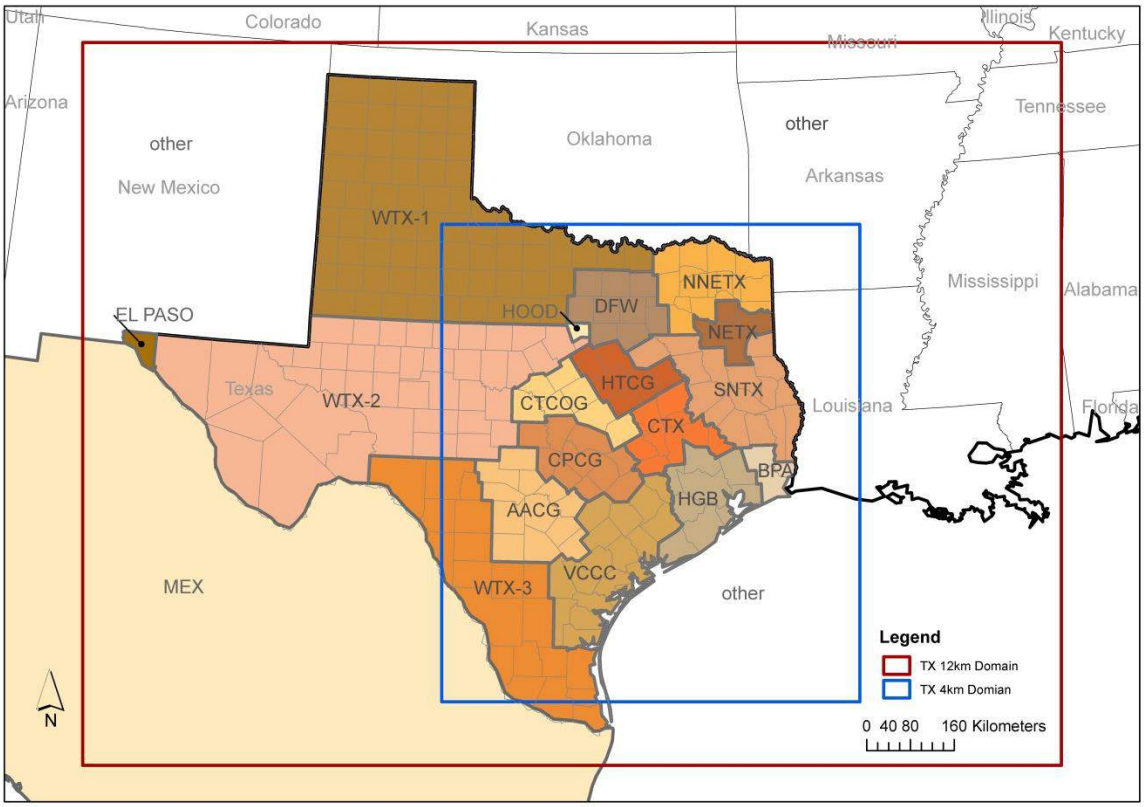


Figure 6-5. APCA source region map with CAMx 12 km (outlined in red) and 4 km (blue) domains.

6.2.2.1 Analysis of Local versus Transported Ozone at KTF Area receptors

The upper panel of Figure 6-6 shows the contribution from local sources and transport to the MDA8 at the Killeen monitor during June 2012. The green bar shows the contribution to the Killeen MDA8 from emissions sources within the 7-county CTCOG region. It is this local ozone contribution shown in green that is amenable to reduction through local emissions controls. The contribution from emissions sources within Texas but outside the KTF region is shown in

gray. The contribution from regions outside Texas (including Mexico) but within the 36 km modeling domain are shown in light blue. The contribution of boundary conditions, that is, air from outside the modeling domain that enters the domain during the modeled time period, is shown in dark blue. Boundary conditions represent contributions from emissions sources outside the U.S. and the contribution from the stratosphere. The boundary condition contribution at Killeen ranges from 12-33 ppb and this is a reasonable range of values for the boundary condition contribution (e.g. McDonald-Buller et al., 2011). The contribution of initial conditions is shown in purple and is less than 0.3 ppb at the beginning of the modeling period. This demonstrates that the model "spinup" (period before June 1 during which the influence of model initial conditions declines) used for this modeling application is sufficient.

The modeled contribution from local sources varies from day to day but is always smaller than the total modeled contributions from transport (sum of all contribution from all regions outside the KTF Area). Local contributions range from less than 1 ppb (11 out of the 30 days) to 12.5 ppb on June 5. On June 5, the contribution from Texas sources outside the KTF region was estimated to account for 12.4 ppb and contributions from emissions sources outside Texas were estimated to account for 4.6 ppb. Boundary conditions were estimated to contribute another 25.2 ppb. These three transport sources combine to comprise 77% of the MDA8 ozone on June 5, which leaves 23% of the total MDA8 of 54.6 ppb estimated to be attributable to KTF emissions sources. However, MDA8 ozone was under-predicted by about 5 ppb on this day, and the local and/or transported contribution could have been underestimated. We suggest further analysis of meteorological and photochemical model performance, along with further emissions inventory review, to determine the cause of this underestimation.

The lower panel of Figure 6-6 shows the CTCOG contributions (green) along with the individual contributions by Texas source region (components of gray bar in the upper panel). These results suggest that emissions from a wide variety of East Texas source regions frequently contribute non-negligible amounts of ozone to the Killeen monitor. Emissions from the CAPCOG region are estimated to contribute more than 5 ppb to MDA8 ozone at the Killeen monitor on 15 days in June 2012, with 8 of these days exceeding 10 ppb. The CAPCOG region lies directly to the south of the KTF region, which suggests that southerly winds are responsible for transporting ozone to the Killeen monitor when CAPCOG contributions are significant. Killeen MDA8 ozone contributions from VCCC (Victoria-Corpus Christi), while smaller than CAPCOG (only 3 days in June 2012 show contributions to MDA8 ozone exceeding 4 ppb), are largest when CAPCOG contributions are significant. This finding makes sense because the VCCC region lies to the south and southeast of the CAPCOG region. Contributions to MDA8 ozone at the Killeen monitor from HGB emissions sources are less than 1 ppb on 18 of the 30 modeled days, but 4 days show contributions larger than 5 ppb, including June 16, which shows a 19 ppb contribution. This suggests that transport from HGB can be important under certain conditions (HGB lies to the southeast of the KTF region). On 5 days (June 7, 8, 22, 25, 26), emissions from HOTCOG (Heart of Texas Council of Governments; Waco area, which lies to the northeast of the KTF region) are estimated to contribute greater than 5 ppb to MDA8 ozone at the Killeen monitor. On these same 5 days, ozone contributions from the SNTX region are highest, suggesting that east-northeasterly winds are responsible for ozone transport on these days.

The ozone contribution from DFW sources is estimated to be relatively small, with a maximum contribution to MDA8 ozone at the Killeen monitor of less than 5 ppb and only 4 days with contributions larger than 1 ppb. While DFW is a significant source of emissions, the location of Bell County (nearly due south of DFW) is not favorable for ozone transport during weather conditions typical of high ozone episodes at Killeen.

Both panels of Figure 6-7 are identical to Figure 6-6 except that they show results at the Temple Georgia monitor instead of Killeen. Similar to Killeen, the boundary condition contribution at Temple Georgia ranges from 12-33 ppb and the initial condition contribution is always smaller than 0.3 ppb. The local contribution to MDA8 ozone at Temple Georgia is generally close to but not exactly the same as the contribution at Killeen. The difference in ozone impacts from local sources at the two monitors on a given day can be explained by the uneven distribution of emissions, which may put one monitor (and not necessarily the other) directly downwind of an emissions source for a given wind direction. We examine the local contributions to ozone at the two monitors in greater detail in Section 6.2.2.2.

Similar to the results at Killeen, the lower panel of Figure 6-7 suggests that emissions from a wide variety of East Texas source regions frequently contribute non-negligible amounts of ozone to the Temple Georgia monitor. For most days, the contributions from the various emissions source regions to the two monitors are quite similar in magnitude, but there are some exceptions. In particular, we observe larger ozone impacts from HOTCOG emissions sources at Temple Georgia and larger ozone impacts from CAPCOG emissions sources at Killeen. Further analysis would be needed to determine the root causes of these differences, but they are likely related to winds which transport plumes from these areas to the KTF counties and cause the plumes to affect one KTF monitor while missing the other. An example of this phenomenon can be seen on June 30: the CAPCOG contribution to MDA8 ozone at the Temple Georgia monitor is only 0.2 ppb and the HGB contribution is 9.6 ppb. The CAPCOG and HGB contributions at the Killeen monitor are 4.8 and 0.3 ppb, respectively. We show spatial plots of ozone impacts on the KTF region in Section 6.2.2.3 that illustrate the importance of wind direction in determining plume impacts on KTF monitors.

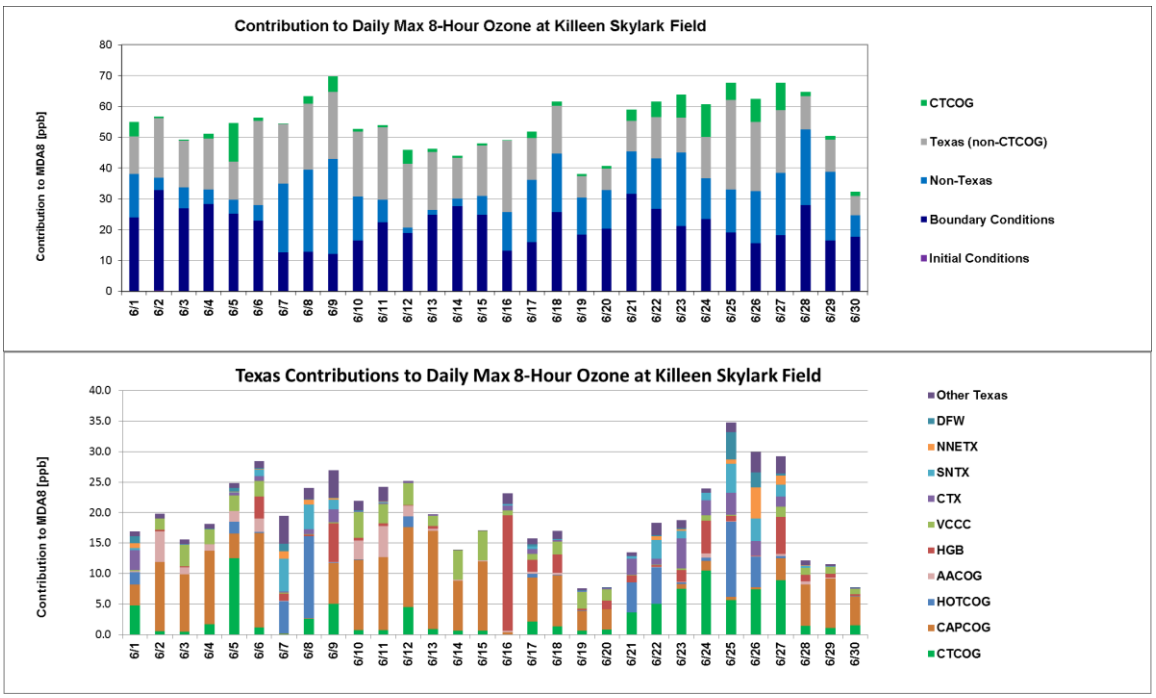


Figure 6-6. Contribution to daily maximum 8-hour ozone by source region for the Killeen monitor. Lower panel shows the individual contributions from selected source regions.

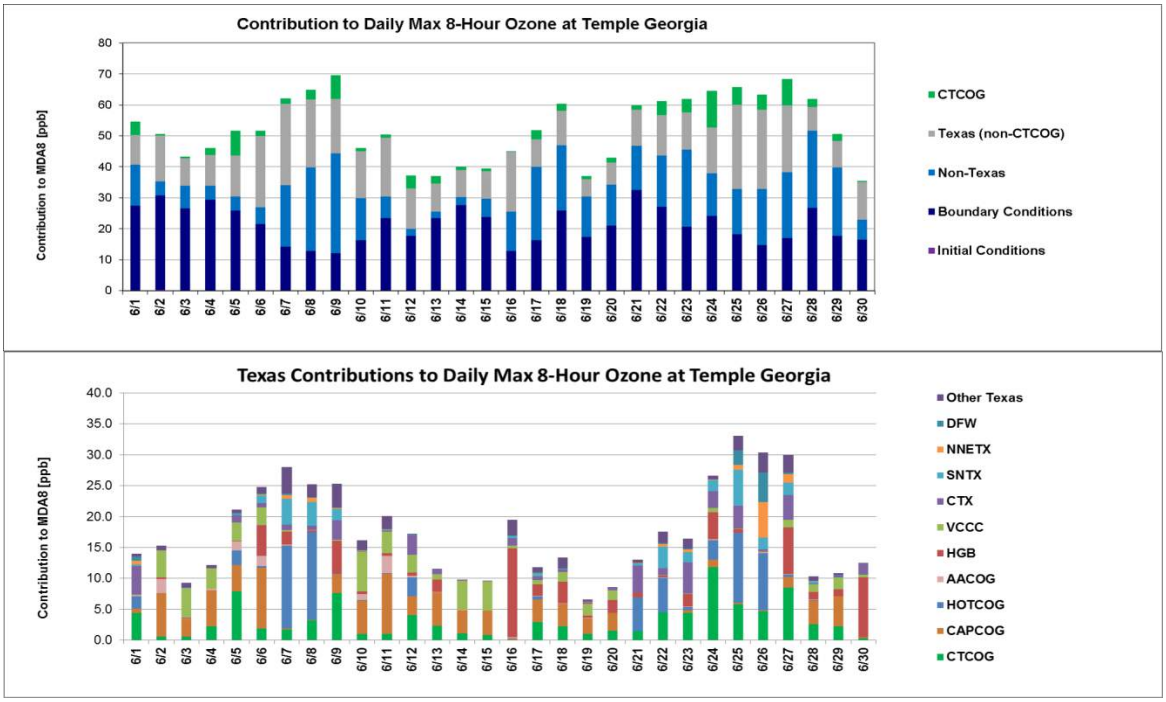


Figure 6-7. Contribution to daily maximum 8-hour ozone by source region for the Temple Georgia monitor. Lower panel shows the individual contributions from selected source regions.

We present episode average contributions to daily maximum 8-hour (MDA8) ozone from local sources and transport in the upper panel of **Figure** 6-8. Receptor locations are provided in Figure 6-9 and are a combination of actual CAMS sites (Killeen and Temple Georgia) and "virtual monitors", where ozone contributions can be tracked without the need for a physical monitoring site. The CAMx source apportionment tool allows us to evaluate ozone contributions to a location even if there is no ozone monitor there. We evaluated population centers in each county of the KTF Area to determine whether source apportionment varied significantly from location to location within the 7-county area. While qualitative results for all receptors are quite similar, there are some differences of 0-4 ppb among the receptors for each given source grouping. For example, the Texas contribution to MDA8 ozone varies from roughly 14 ppb at Temple Georgia to about 17 ppb at CRV2 (Coryell Virtual Monitor #2). Some of this variation is explained by relatively larger CAPCOG contributions observed at LAMV (Lampasas Virtual Monitor), CRV2 and Killeen and HGB contributions at MLMV (Milam Virtual Monitor).

The lower panel of **Figure** 6-8 presents the same information as the upper panel except that the three transport sources (IC+BC, Texas and outside Texas) are combined into a single category. Consistent with the daily contribution analysis, episode average contribution from local sources is small in comparison to transport with less than 6% (range among 9 receptors is 2 to 6%) of the MDA8 ozone at the Killeen monitor attributed to CTCOG emissions sources. In contrast, transport from other Texas regions contributes about 30% (receptor range is 27 to 32%) to episode average MDA8 ozone at the Killeen monitor.

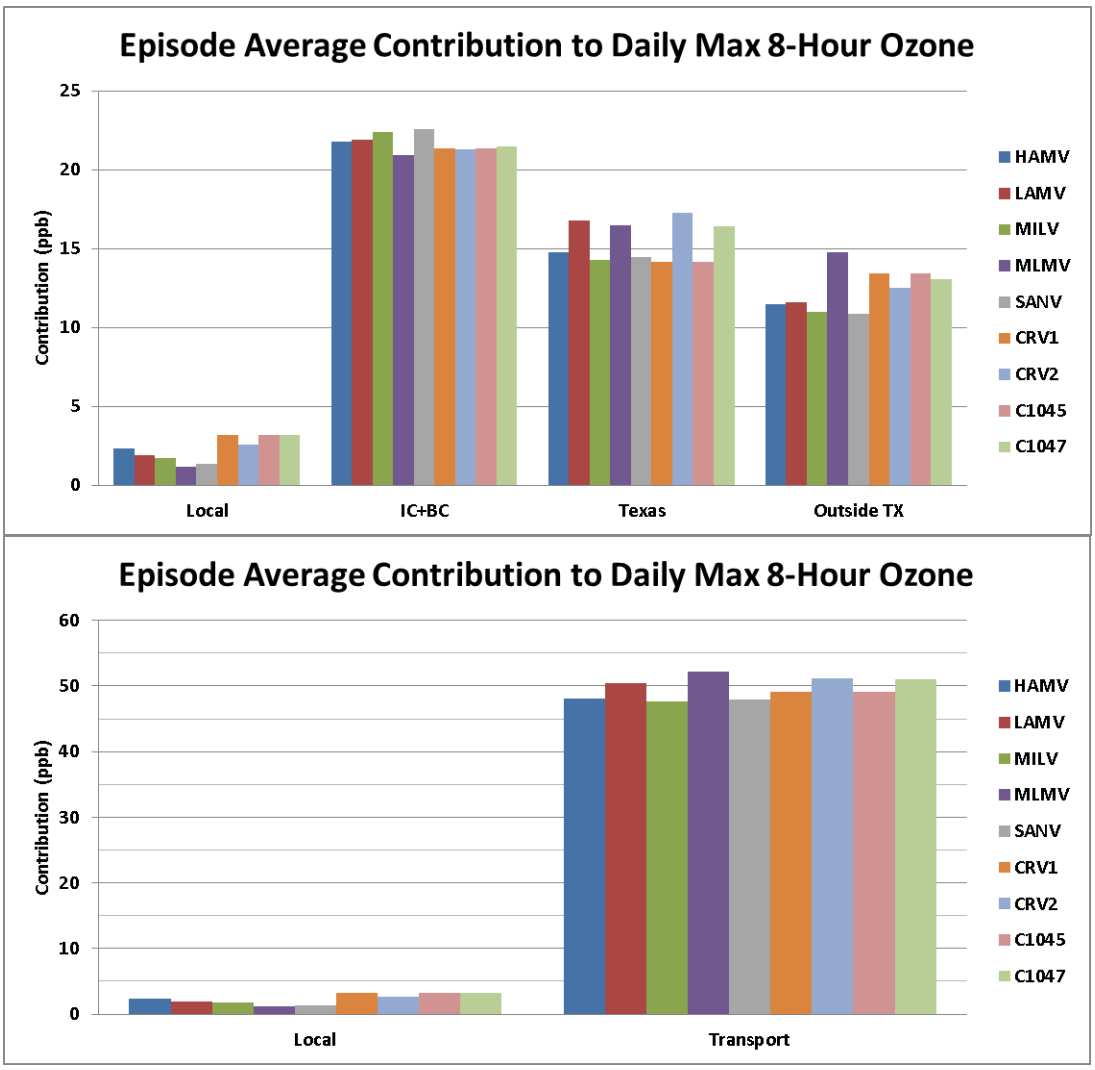


Figure 6-8. Episode average contribution to daily maximum 8-hour ozone for 9 receptors in the KTF region. The lower panel groups the three non-local contributions (Initial Conditions+Boundary Conditions, Texas and Outside Texas) into a single category (Transport).

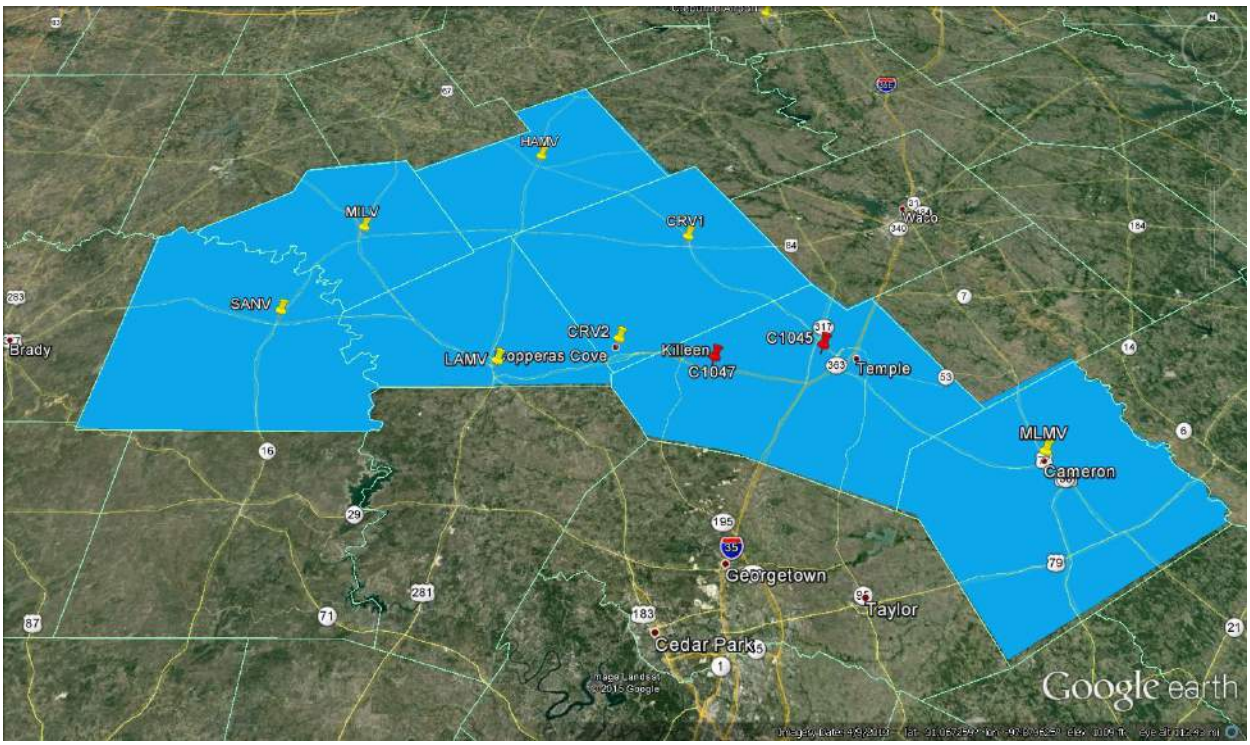


Figure 6-9. Map of receptor locations shown in Figure 6-8. Killeen and Temple Georgia CAMS monitors are shown with red icons and virtual monitors are shown as yellow icons.

6.2.2.2 Description of Local Emissions Sources Influencing Ozone at the Killeen and Temple Georgia Monitors

Figure 6-10 shows the breakdown by day of the local contribution (the green part of the bar in Figure 6-6) by contribution from each emissions source category. Oil and gas (O&G) refers to the contribution from emissions from O&G area sources. "Area" refers to all area sources that are not related to O&G exploration and production (e.g. consumer products, dry cleaners, solvent use). The magnitude of the contribution from each category of emissions fluctuates from day to day. For example, the contribution from elevated point sources is near 2 ppb on June 27 but drops to less than 0.2 ppb the following day. The impact of point sources on the monitor is highly variable because whether the plume from the point source reaches the monitor depends on wind direction and the altitude of the plume. Contributions from source categories that are distributed in space, such as on-road mobile and non-road mobile, are less variable in time.

Figure 6-11 is identical to Figure 6-10, but replaces the Killeen monitor with the Temple Georgia monitor. The relative contributions are similar, but there is slightly more impact from oil and gas emissions sources compared to Killeen. On June 3, the Temple Georgia monitor shows less ozone impact from on-road and off-road mobile sources, leading to a lower overall local ozone contribution. On June 9, we observe a larger EGU contribution to MDA8 ozone at the Temple Georgia monitor (3 ppb vs. less than 2 ppb at Killeen). The non-road mobile ozone contribution

is also larger at Temple Georgia on June 9, leading to a local emissions contribution of 3 ppb greater than seen at Killeen on the same day.

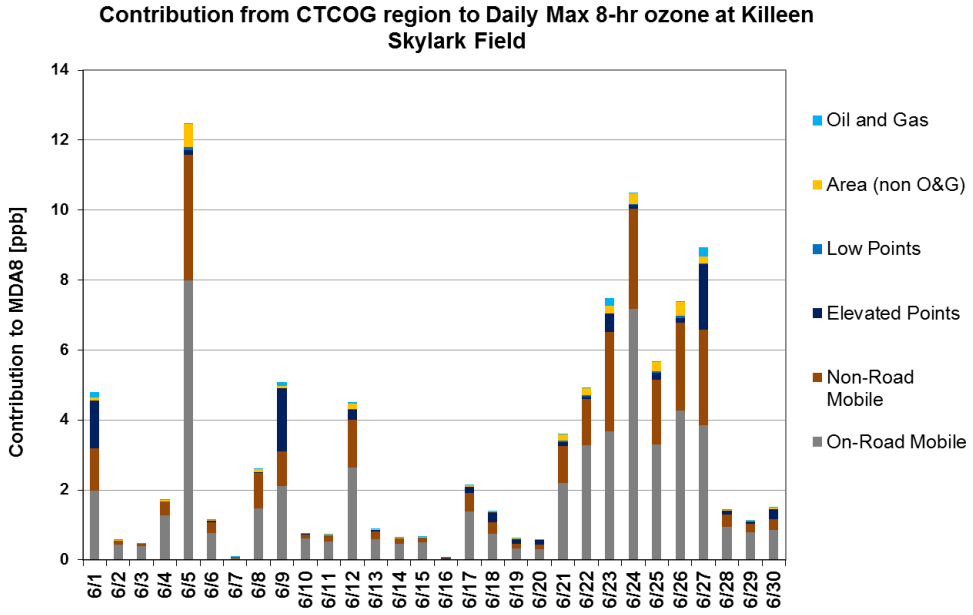


Figure 6-10. Killeen detailed source apportionment for local contribution shown in green in Figure 6-6.

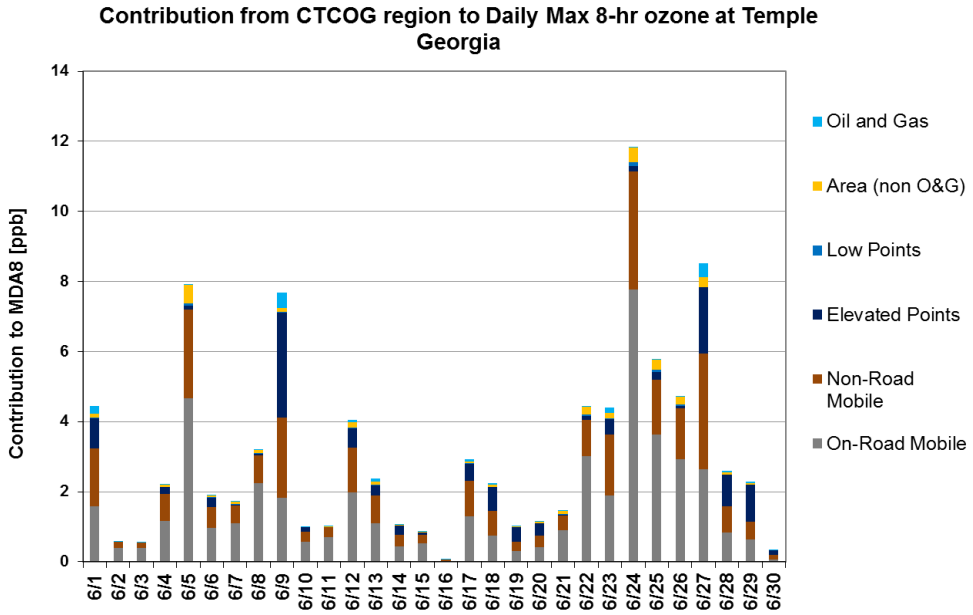


Figure 6-11. Temple Georgia (CAMS 1045) detailed source apportionment for local contribution shown in green in Figure 6-7.

The upper panel of Figure 6-12 shows the same detailed breakdown of CTCOG ozone contributions for the Killeen monitor as in Figure 6-10 except the daily contributions are

replaced with episode average contributions. On-road mobile emissions contribute most to the episode average MDA8, but it is less than 2 ppb. All other local sources contribute less than 1 ppb.

The lower panel is identical to the upper panel except that data are shown for the episode maximum instead of episode average. The largest episode maximum contribution is 8 ppb and comes from the on-road mobile category. The Killeen monitor is located less than a mile north of heavily-trafficked Highway 190, which connects the Killeen-Fort Hood Area with Belton and Temple and Interstate I-35. I-35 is approximately 13 miles west of the Killeen monitor, and is a major highway that has a high volume of automobile and heavy-duty truck traffic.

Episode maximum contributions for on-road mobile, non-road mobile and area (non-oil and gas) all occur on June 5, when the total CTCOG contribution is highest. The largest contribution from elevated points is 1.9 ppb and occurs on June 27. CAMx under-predicts ozone on this day and this may be the result of the model mischaracterizing the extent or orientation of the plume relative to the monitoring location.

Figure 6-10 through Figure 6-12 show that local KTF emissions sources can produce intermittent large impacts at the Killeen monitor up to 12 ppb. These impacts are of particular concern because they have the potential to drive up the DV by affecting the monitor on dates that enter into the DV calculation.

Figure 6-13 is identical to Figure 6-12, but replaces the Killeen monitor with the Temple Georgia monitor. The episode average contributions to MDA8 ozone are similar to those of the Killeen monitor. For the episode maximum contributions at Temple Georgia (lower panel of Figure 6-13), results are nearly identical for all local emissions sources except elevated points: the contribution from this sector is about 1 ppb larger than the elevated point source contribution at Killeen.

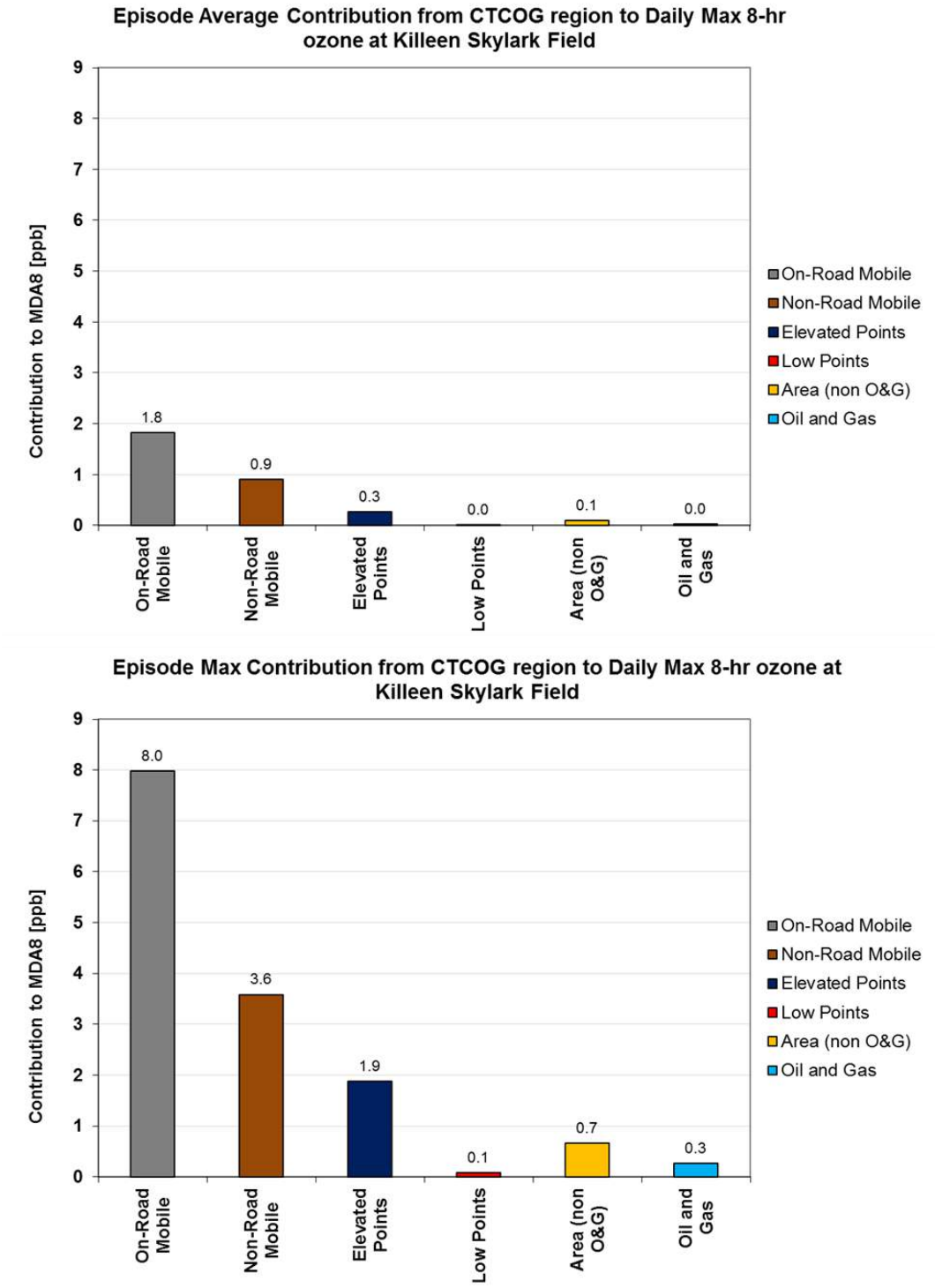


Figure 6-12. Killeen detailed source apportionment for local contribution for episode average (upper panel) and episode maximum (lower panel) contribution to daily maximum 8-hour ozone.

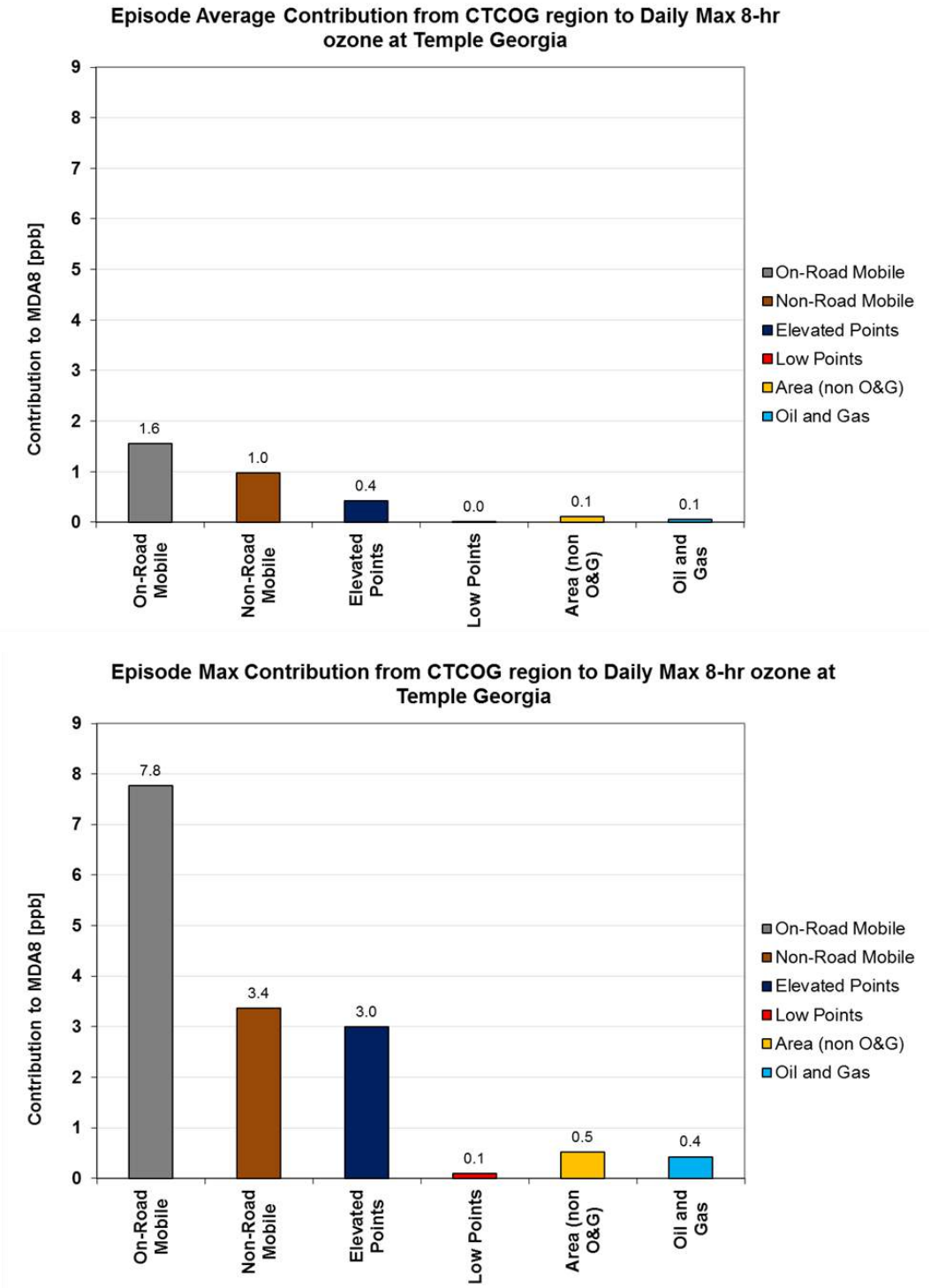


Figure 6-13. Temple Georgia detailed source apportionment for local contribution for episode average (upper panel) and episode maximum (lower panel) contribution to daily maximum 8-hour ozone.

Figure 6-12 and Figure 6-13 show only results for the locations of the Killeen and Temple Georgia monitors respectively and ozone impacts vary across the 7-county KTF region. In Figure 6-14 we present a spatial plot that depicts ozone impacts of EGUs (power plants) at locations away from the monitors as well as at the monitors. Figure 6-14 shows for each grid cell the episode maximum contribution to the MDA8 during the episode from EGUs in the KTF region; the only EGU active in the KTF region during June 2012 was the Sandow Generating Station in Milam County. The plot shows the boundaries of the 7-county CTCOG region as thick black lines and monitor locations for Killeen and Temple Georgia within Bell County along with Waco Mazanec (CAMS1037), Austin Northwest (CAMS 3) and Northwest Harris County (CAMS 26); the monitor locations are shown as circles.

Episode maximum ozone contributions from the Sandow Generating Station are located directly to the west of the source extending into Williamson County and are approximately 10-12 ppb. Plumes of smaller magnitude (cyan color in Figure 6-14; 2-3 ppb) extend into Bell and Coryell Counties. The Temple Georgia monitor is located within this plume, while the Killeen monitor is just outside the edge of the plume. This explains the difference in episode maximum EGU ozone impacts found in the lower panels of Figure 6-12 and Figure 6-13.

The “fanning” of ozone contributions in different directions reveals various wind regimes present during the June 2012 episode that put different regions downwind of the Sandow emissions plume at different times.

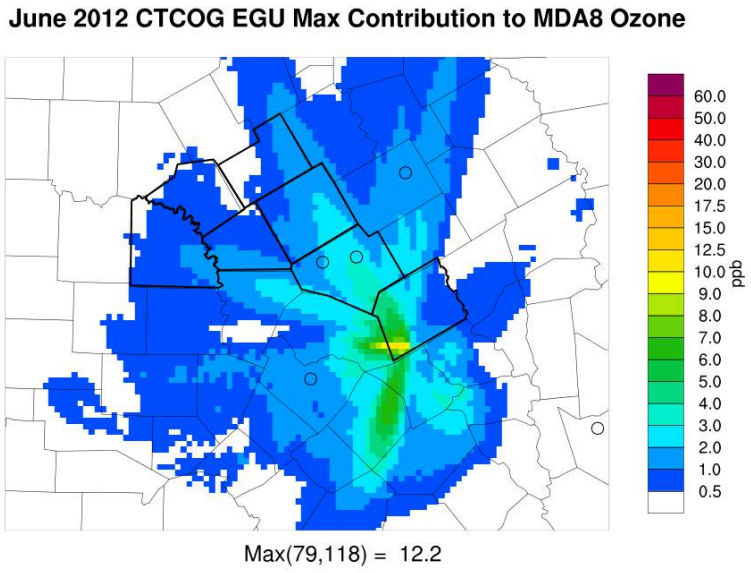


Figure 6-14. Episode maximum contribution to daily maximum 8-hour ozone from CTCOG EGU emissions source (Sandow Generating Station). Monitor locations for Killeen and Temple Georgia within Bell County along with Waco Mazanec (CAMS 1037), Austin Northwest (CAMS 3) and Northwest Harris County (CAMS 26) shown as circles.

Ozone impacts of Sandow emissions were higher (episode maximum of 12 ppb) away from the Killeen monitor. The location of the Sandow plume varied from day to day based on the wind direction and during the June 2012 episode, and the highest Sandow ozone impacts occurred to the south and east of the plant. The modeling results indicate that during different wind conditions than occurred during this 1-month episode, it would be possible for the Sandow plume to influence the Killeen and Temple Georgia monitor MDA8 values at a higher level (up to 4 ppb). We therefore recommend that SO_2 monitoring be performed at Killeen and Temple Georgia. Coal-fired power plant plumes are characterized by the presence of SO_2, which is released into the air during combustion of coal. The presence or absence of SO_2 along with ozone in a plume can therefore help identify whether a coal-fired power plant influenced a monitor on a high ozone day.

The Panda Temple Power Project is a new natural gas-fueled combined-cycle power plant located in Temple. The facility is being built in two phases, with each phase consisting of two combustion turbines and one steam turbine with total capacity of 758 MW, so that the entire facility will have capacity of 1516 MW. Construction on the first phase of the project, the Panda Temple I Generating Station, began in 2012. Panda Temple I commenced operations in July 2014. Construction on the second phase of the Project, Panda Temple II Generating Station, began in April 2013 and Phase II is projected to be operational by the end of 2015.

The Panda Temple facility was not operational in 2012 and is not present in the 2012 TCEQ ozone modeling emission inventory. Therefore, its ozone impacts were not evaluated in this study. We recommend that an analysis of emissions from the facility be performed in the future. If NOx emissions appear significant, then the potential ozone impacts of this facility should be modeled in order to understand its influence on ozone at the Temple Georgia and Killeen ozone monitors.

6.2.2.3 Comparison of Regions Influencing Ozone at the Killeen Monitor

We present episode average ozone contributions at the Killeen monitor broken down by region in the upper panel of Figure 6-15. As seen in **Figure** 6-8, the largest contributions come from initial and boundary conditions (IC + BC; 22 ppb) and from regions outside Texas (13 ppb). The IC + BC contribution (22 ppb) represents transport of ozone from sources outside the CAMx modeling domain (see Figure 6-3) and is consistent with the global background concentration for ozone. The contribution from outside Texas (13 ppb) represents ozone transport from other states and portions of Mexico that are within the CAMx modeling domain. The largest contribution from within Texas comes from CAPCOG and is roughly 6 ppb. CAPCOG (6.1 ppb) is the only Texas region that contributes more ozone to the Killeen monitor than local sources (3.2 ppb). An additional 6 Texas regions contribute around 1-2 ppb each (HGB, HOTCOG, VCCC, SNTX, Central Texas and AACOG). All other Texas regions contribute less than 0.5 ppb.

The lower panel of Figure 6-15 presents the same information as the upper panel, except the chart shows the episode maximum contribution to MDA8 ozone instead of the episode average. We note considerable differences in the magnitudes of the episode maximum contributions as compared with the episode average contributions. This agrees with the daily

contributions by Texas source region (Figure 6-6), where large day-to-day variation in Texas regions impacting ozone were found at the Killeen monitor.

The episode maximum contribution from outside Texas is 33 ppb, an increase of 20 ppb over the episode average contribution. HGB has the largest contribution to MDA8 ozone at the Killeen monitor (19.8 ppb), while the same contribution is only 1.9 ppb for the episode average. As seen in the daily contribution plots, the contribution from HGB is near zero on most days, bringing the episode average contribution down. Aside from HGB, there are two additional Texas regions with episode maximum contributions larger than local sources (12.5 ppb): CAPCOG (16.1 ppb) and HOTCOG (13.4 ppb). Considering the relatively small magnitude of emissions generated within the KTF region (Grant et al., 2015), it is not surprising that HGB, CAPCOG and HOTCOG all have the potential to contribute more ozone (via transport) to the Killeen monitor than is generated by local KTF emissions sources. For all other Texas regions, the episode maximum contributions to MDA8 ozone at the Killeen monitor are around 5 ppb or less. These regions include Northeast Texas (SNTX and NNETX), AACOG, Central Texas and Victoria/Corpus Christi.

Figure 6-15. Killeen Skylark field (CAMS 1047) detailed source apportionment by region for the episode average (upper panel) and episode maximum (lower panel) contribution to daily maximum 8-hour ozone.

We present episode maximum contributions to MDA8 ozone by emissions source region in Figure 6-16. We chose these specific source regions because they showed the largest ozone impacts to the KTF receptor locations. Each of the six panels is similar to the spatial plot in Figure 6-14, except that ozone impacts from all anthropogenic emissions sectors for each emissions source region are combined. For reference, monitor locations for Killeen and Temple Georgia within Bell County along with Waco Mazanec, Austin Northwest and Northwest Harris County are shown as circles.

The CTCOG plot (panel A) shows the highest contributions in the vicinity of the Sandow Generating Station in the southwest portion of Milam County, with contributions to MDA8 ozone exceeding 15 ppb. Contributions are slightly higher near the Killeen monitor as compared to the Temple Georgia monitor; this agrees with the daily contribution breakdown in of local emissions sources in Figure 6-10 and Figure 6-11. The ozone contribution from CTCOG emissions sources is generally highest within and immediately downwind of the most populous counties: Bell and Coryell. The influence of the Killeen and Temple urban plumes is apparent in Figure 6-16. Outside the KTF region, episode maximum ozone contributions of around 2 ppb from KTF Area emissions are found near the Waco Mazanec monitor and roughly 5 ppb near the Austin Northwest monitor.

Panel B (CAPCOG) shows a larger ozone impact due to CAPCOG emissions at the Killeen monitor as compared to the Temple Georgia monitor. Portions of the 7-county CTCOG area show CAPCOG contributions to MDA8 ozone exceeding 20 ppb, including Bell County near the Killeen monitor. Lampasas and San Saba Counties are also shows ozone contributions up to 20 ppb from CAPCOG emissions. Panel C (HOTCOG) shows ozone impacts exceeding 20 ppb in Milam County (impacts from the Limestone EGU and surrounding oil and gas development) and Coryell County (Waco urban plume). Small changes in wind direction could result in the Bell County monitors picking up significantly larger amounts of ozone from the HOTCOG region. Panel D (HGB) shows the 19 ppb contribution to MDA8 ozone at Killeen seen previously and the sharp gradient directly east of the monitor that results in significantly lower contributions at the Temple Georgia monitor. Panels E (NNETX) and F (SNTX) show ozone impacts from the two Northeast Texas regions and have significantly lower impacts than the other Texas regions shown previously. But the patterns of ozone contributions suggest that either of these regions can contribute up to 8-9 ppb to MDA8 ozone to one of the Bell County CAMS monitors during periods of persistent easterly and/or east-northeasterly wind flow.

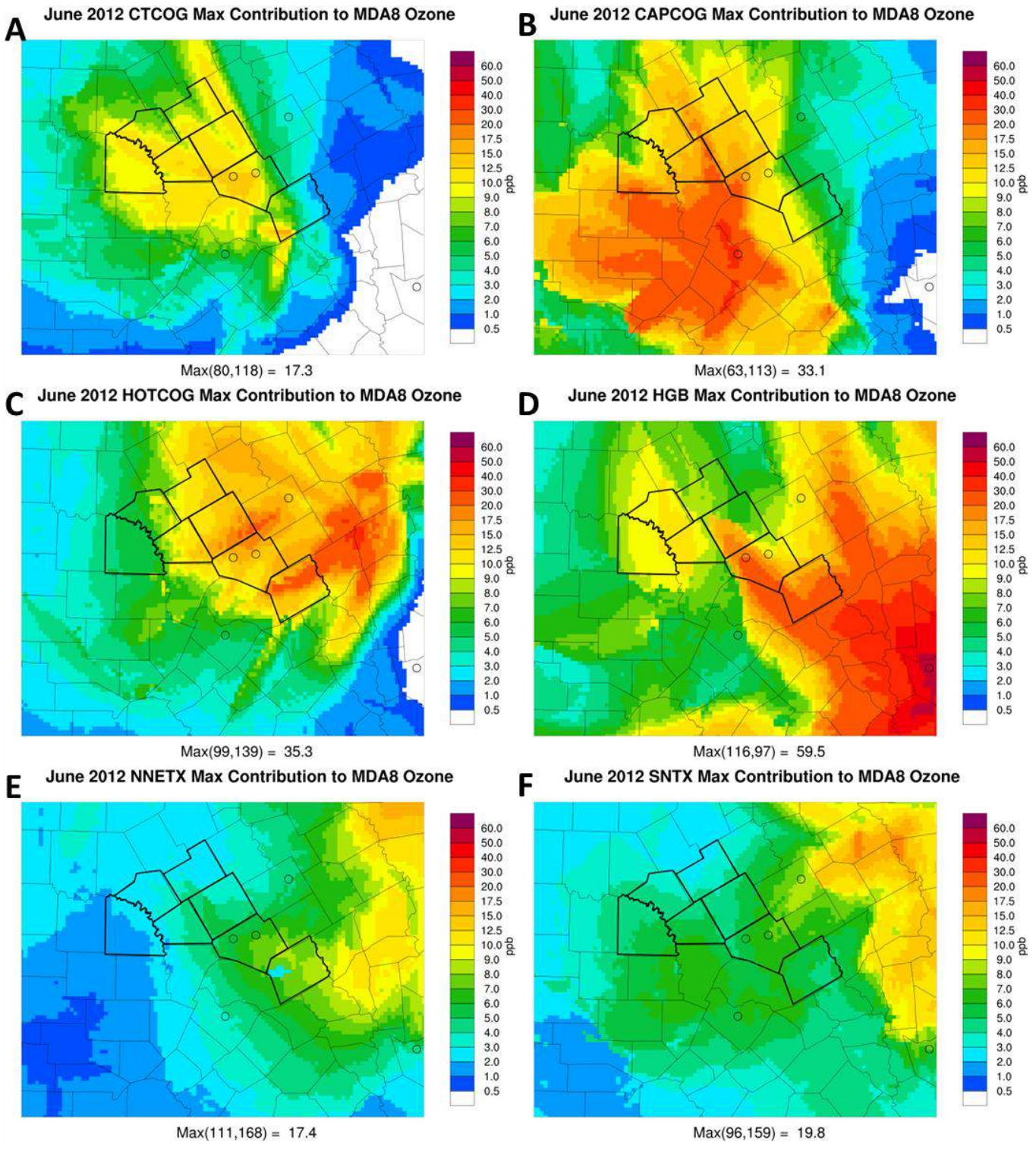


Figure 6-16. Episode maximum contribution to daily maximum 8-hour ozone from A) CTCOG, B) CAPCOG, C) HOTCOG, D) HGB, E) NNETX, and F) SNTX emissions sources. Monitor locations for Killeen and Temple Georgia within Bell County along with Waco Mazanec (CAMS 1037), Austin Northwest (CAMS 3) and Northwest Harris County (CAMS 26) shown as circles.

6.2.2.4 Analysis to Determine if Ozone is NOx- or VOC-limited

As mentioned previously, the CAMx APCA methodology estimates fractions of ozone arriving at a given receptor that were formed en-route under VOC- or NOx-limited conditions. This information suggests whether ozone concentrations at the receptor may be responsive to reductions in VOC and NOx precursor emissions and can guide development of emissions control strategies and additional sensitivity analyses.

In Figure 6-17 and Figure 6-18, we present episode average (upper panel) and episode maximum (lower panel) CTCOG contributions to daily max 8-hour ozone at the Killeen and Temple Georgia monitors, respectively. Contributions are categorized by the nature of ozone formation en route to the monitor (NOx versus VOC-limited) and emissions category (elevated points versus anthropogenic surface emissions). Biogenic and fire (i.e. uncontrollable) emissions are excluded. Episode average contributions are segregated by MDA8 threshold: blue bars represent no threshold, red bars represent a 60 ppb threshold and green bars represent a 75 ppb threshold. We apply these thresholds to quantify contributions on days when MDA8 ozone exceeds 60 and 75 ppb; these values are chosen because they coincide with the current ozone NAAQS and the lowest level of the NAAQS on which EPA is currently accepting comments. We note that the model does not predict MDA8 ozone greater than or equal to 75 ppb at either monitor. No threshold is applied to episode maximum contributions in the lower panel.

CTCOG emissions contributions for all thresholds and source categories indicate that ozone is formed almost exclusively under NOx-limited conditions. This means that anthropogenic NOx emissions are more important in determining the amount of ozone formed than anthropogenic VOC emissions. This outcome is expected because biogenic VOC emissions are abundant in the area so that there are typically sufficient VOC available for ozone formation (Grant et al., 2015). When the MDA8 threshold is raised from 0 to 60 ppb, average contributions expressed as ozone concentrations (ppb) from CTCOG also increase, but the result that ozone formation in the KTF Area is NOx-limited is unchanged.

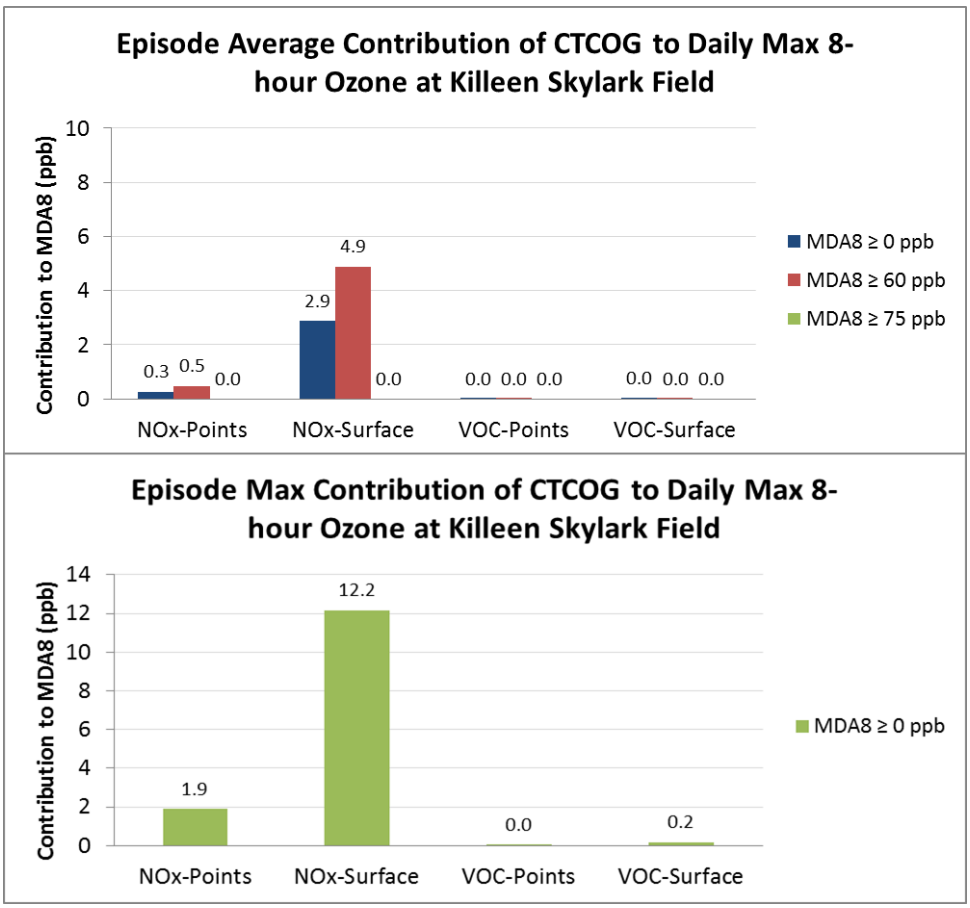


Figure 6-17. Episode average (upper panel) and episode maximum (lower panel) CTCOG contributions to the daily max 8-hour ozone contributions at the Killeen monitor. Contributions are categorized by the nature of ozone formation en route to the monitor (NOx versus VOC-limited) and emissions category (elevated points versus anthropogenic surface emissions). Episode average contributions are segregated by MDA8 threshold: blue bars represent no threshold, red bars represent a 60 ppb threshold and green bars represent a 75 ppb threshold. No threshold is applied to episode maximum contributions in the lower panel.

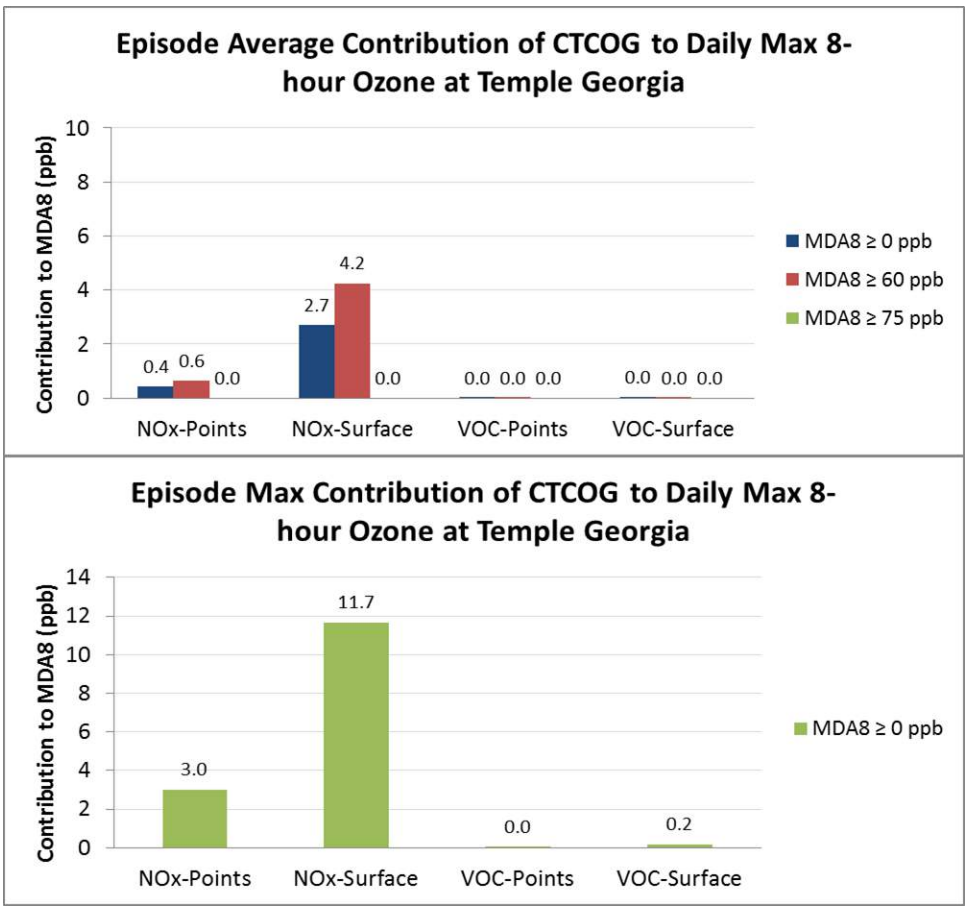


Figure 6-18. Episode average (upper panel) and episode maximum (lower panel) CTCOG contributions to the daily max 8-hour ozone contributions at the Temple Georgia monitor. Contributions are categorized by the nature of ozone formation en route to the monitor (NOx versus VOC-limited) and emissions category (elevated points versus anthropogenic surface emissions). Episode average contributions are segregated by MDA8 threshold: blue bars represent no threshold, red bars represent a 60 ppb threshold and green bars represent a 75 ppb threshold. No threshold is applied to episode maximum contributions in the lower panel.

6.2.2.5 Analysis of CTCOG Ozone Contributions at Monitors in Other Regions

We present an analysis of episode average CTCOG contributions to MDA8 ozone at the Killeen and Temple Georgia monitors along with selected monitors in the Waco, Dallas-Fort Worth, Tyler, Austin and Houston regions in Figure 6-19. We selected these monitors to measure the impact of CTCOG emissions on ozone at nearby and distant Texas monitors. Blue bars represent episode average contributions calculated only for days where MDA8 ozone exceeded 60 ppb. Red bars represent episode average contributions calculated only for days where the MDA8 ozone exceeded 75 ppb. As mentioned previously, the model does not predict any days with MDA8 ozone equal to or greater than 75 ppb during June 2012 at either the Killeen or Temple Georgia monitors.

As expected, the largest contributions are observed at the Killeen and Temple Georgia monitors at around 5 ppb each. Note that these values differ from the episode average CTCOG contributions to MDA8 ozone presented previously – the higher CTCOG ozone impacts in Figure 6-19 result from including only the days where the MDA8 ozone exceeds the 60 ppb threshold. The most significant impacts outside the KTF region are observed at Austin area receptors to the south: Hutto College St. (2.7 ppb), Lake Georgetown (2.5 ppb), followed by Audubon (1.7 ppb) and Austin Northwest (1.3 ppb). All other monitors show significantly lower CTCOG contributions when the threshold is increased to 75 ppb, with the exception of Austin Northwest, which increases slightly to 1.6 ppb. All other monitors show episode average CTCOG contributions of 0.5 ppb or less.

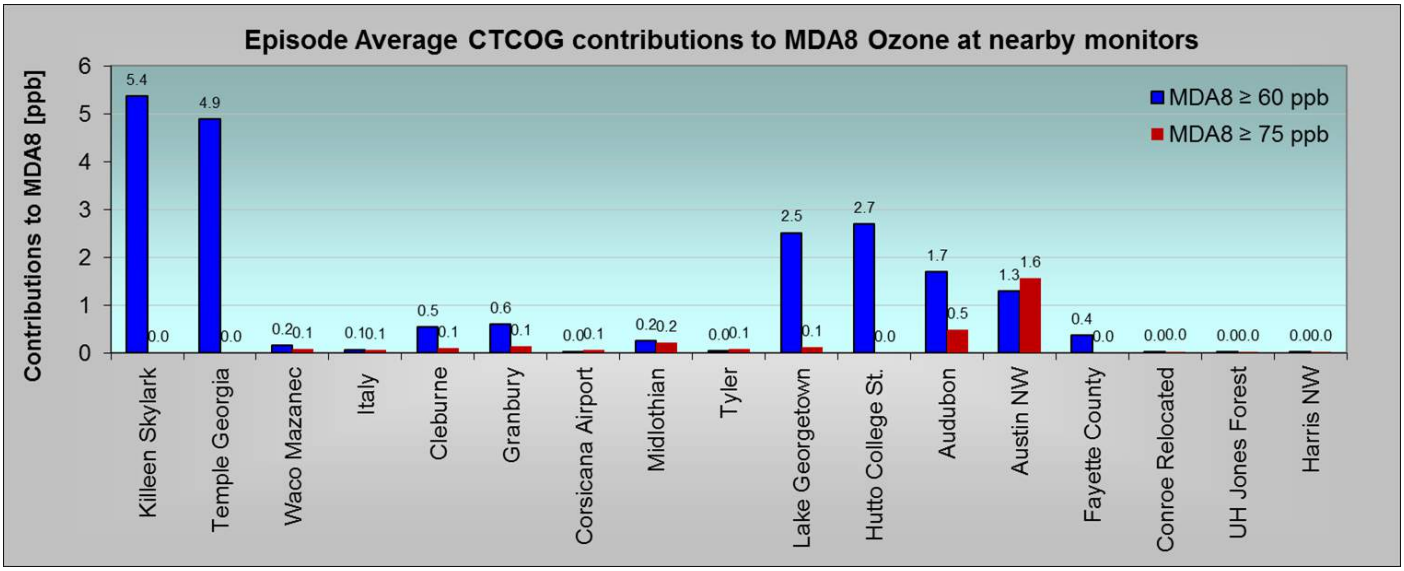


Figure 6-19. Episode average contributions from CTCOG to the Killeen monitor and other nearby monitors in the Waco, Austin, Dallas-Fort Worth and Houston regions. Blue bars represent episode average contributions calculated only for days where daily maximum 8-hour ozone exceeded 60 ppb. Red bars represent episode average contributions calculated only for days where daily maximum 8-hour ozone exceeded 75 ppb.

6.3 Conclusions and Recommendations for Future Work

In this section, we summarize ozone model performance results at the Killeen monitor (Section 6.3.1) and APCA ozone contribution analysis at receptor locations within KTF region (Section 6.3.2). Finally, we present recommendations for future work (Section 6.3.3).

6.3.1 Ozone Model Performance Results

Our evaluation of photochemical model performance at the Killeen monitor shows that the model captures much of the observed ozone variability and has an overall high bias, but underestimates peak ozone by as much as 16 ppb on days when ozone exceeds 70 ppb. These low biases may result from underestimates in the local KTF emissions sources and/or errors in

modeled winds. While these biases can affect the details of the model results, they should not significantly affect the qualitative nature of the ozone source apportionment analysis presented in this report. Determining the exact causes for the ozone under-predictions requires further diagnosis and should be a focus of future work.

6.3.2 APCA Ozone Contribution Analysis at KTF Receptors

We performed an analysis of the source apportionment model for an ozone episode in June 2012 focusing on modeled contributions to ozone at receptor locations within the 7-county KTF region. We quantified the contribution from regions within and outside Texas to ozone at the receptor locations for each day of the June 2012 episode. We also evaluated the contribution of KTF emissions to MDA8 ozone at the Killeen and Temple Georgia monitors and separated the contribution from KTF emissions at each monitor into contributions from different emissions source categories.

The APCA results showed that, on average, transport contributes far more to KTF ozone than emissions from local KTF Area sources. The contribution of emissions from within the KTF Area accounts for about 3 ppb of the episode average 8-hour ozone at the Killeen monitor while CAPCOG contributes 6 ppb. On a day-to-day basis, the local ozone contribution to MDA8 ozone from KTF Area emissions reached a maximum value of 12.5 ppb at the Killeen monitor, while three Texas regions (HGB, CAPCOG and HOTCOG) each contributed larger amounts (19 ppb, 16 ppb and 13 ppb, respectively).

The breakdown of ozone impacts by emissions source categories indicates that on-road mobile emissions make the largest episode maximum contribution to ozone at the Killeen and Temple Georgia monitors, though their episode average contribution is about 2 ppb. The episode average contribution from off-road mobile emissions is about 1 ppb at each monitor. Episode maximum ozone impacts from EGU emissions are about 3 ppb at Temple Georgia and close to 2 ppb at Killeen. However, ozone impacts from the Sandow Generating Station in Milam County are higher (episode maximum 12.2 ppb) at other locations nearby Sandow that experience plume impacts from this facility during the June 2012 episode. All other local emissions categories made relatively small contributions (0.5 ppb or less on average) to the daily maximum 8-hour ozone.

The breakdown of ozone impacts by source region shows specific Texas regions that contribute most to elevated ozone levels at the Killeen monitor. While HGB shows the highest contribution from within Texas, there are 2 additional Texas regions that contribute more ozone to the Killeen monitor than local KTF emissions sources: CAPCOG and HOTCOG. There is a significant amount of day-to-day variation in ozone contribution from the various Texas source regions. Spatial plots of ozone impacts by source region typically show higher contributions within the 7-county area than is observed at the Killeen and Temple Georgia monitors. This finding suggests that small changes in winds could significantly affect the magnitude of ozone impacts from other Texas source regions.

The CAMx APCA methodology estimates fractions of ozone arriving at a given receptor that were formed en-route under VOC or NOx-limited conditions. We utilize this information to determine whether ozone will be responsive to reductions in VOC and NOx precursor emissions. We conclude from our analysis of KTF ozone contributions that NOx-limited conditions exist almost exclusively when ozone is being formed from KTF emissions sources en route to the Killeen and Temple Georgia monitors. Therefore, KTF Area ozone will be more responsive to reductions in NOx emissions than VOC emissions. This finding is consistent with the fact that abundant biogenic VOC emissions are present in the KTF region. Because the KTF region is greatly influenced by transported ozone, we expect that reductions in NOx emissions in surrounding regions can have a larger overall effect in reducing ozone at the Killeen monitor than emissions reductions from KTF sources.

Finally, we analyzed the KTF contributions to ozone at nearby monitoring locations in the Houston-Galveston-Brazoria, Dallas-Fort Worth, Austin and Waco regions. The largest ozone impacts are observed at the Hutto College Street (2.7 ppb) and Lake Georgetown (2.5 ppb) monitors when the MDA8 is equal to or greater than 60 ppb. Ozone impacts from KTF emissions exceed 1 ppb at two additional monitors (Audubon and Austin Northwest). This result shows that KTF emissions make a small contribution to the MDA8 ozone at nearby monitoring locations.

6.3.3 Recommendations for Future Work

The following tasks are a high priority for future ozone modeling studies for the KTF region:

- Diagnose cause(s) of the June 2012 ozone model's low bias on high ozone days at Killeen and improve model performance on these days
- Perform a complete Weather Research and Forecast (WRF) meteorological model performance evaluation at the Killeen monitor and other airport weather monitoring stations within the 7-county area. The KTF Area is greatly influenced by transported ozone, and wind speed and wind direction errors can contribute to ozone biases at the Killeen monitor.
- Perform a more complete ozone model performance evaluation that examines representative monitors in Texas regions that significantly contribute to ozone in the KTF region. Since the KTF region is strongly influenced by transported ozone, it is important to accurately predict ozone formed outside of the KTF region.
- Review ozone precursor emissions and estimate ozone impacts from the new Panda Temple Power Generating Station, which is located in Bell County approximately 8 miles southeast of the Temple Georgia ozone monitor. Because the Panda Temple Station was not yet operating in 2012, its impacts on KTF Area ozone were not evaluated in this study.

7.0 RECOMMENDATIONS

Based on the analyses performed, the following items are recommended for future work:

7.1 Emissions Recommendations

- Emissions from Fort Hood military post off-road equipment, area sources, on-road vehicles, and point sources are uncertain. Specific sources of uncertainty that should be addressed are off-road emissions from sources such as military tanks, armored vehicles, and helicopters; industrial area sources (e.g. solvent usage, degreasing); on-base on-road vehicle emissions; and thresholds that were used to determine which emission sources were reported in the Fort Hood point source emission inventory. *(High priority)*
- An analysis of emissions from the new Panda Temple I and II Generating Stations should be performed. If NOx emissions appear significant, then the potential ozone impacts of this facility should be modeled in order to understand its influence on ozone at the Temple Georgia and Killeen ozone monitors. *(High priority)*
- For the following oil and gas source categories: artificial lift (pumpjack) engines, fugitives components, crude oil storage tanks, heaters, well venting (blowdowns), and well completions, emission calculation assumptions are generally based on potentially outdated studies or not based on data that encompasses recent drilling and production activity in the KTF Area and should be updated. *(Medium priority for artificial lift engines, low priority for all other sources)*
- Gasoline distribution volume estimates should be obtained from the Texas Comptroller's office to verify that reasonable gasoline throughput volumes are used in the ERG (2008a) study. Obtaining annual gasoline throughput estimates from the Texas Comptroller's office and comparing those throughput estimates to throughput estimates in ERG (2008a) is likely to require minimal effort. *(Low priority)*

7.2 Monitoring Recommendation

- NOx and SO_2 monitoring at one or more KTF Area CAMS sites. *(Medium priority)*
  - NOx and SO_2 are not currently monitored at Killeen (CAMS 1047) or Temple (CAMS 1045) and it is recommended that NOx and SO_2 monitoring be added to those sites. NOx measurements will allow a more in-depth analysis of the effects of on-road mobile sources, as well as discern future KTF Area NOx trends. SO_2 monitoring will allow a better determination of potential sources, particularly coal-fired power plants that may influence high ozone in the KTF Area.

7.3 Photochemical Modeling Recommendations

- Diagnose cause(s) of the June 2012 ozone model's low bias on high ozone days at Killeen and improve model performance on these days *(High priority)*
- Perform a complete Weather Research and Forecast (WRF) meteorological model performance evaluation at the Killeen monitor and other airport weather monitoring

stations within the 7-county area. The KTF Area is greatly influenced by transported ozone, and wind speed and wind direction errors can contribute to ozone biases at the Killeen monitor. *(High priority)*

- Perform a more complete ozone model performance evaluation that examines representative monitors in Texas regions that significantly contribute to ozone in the KTF region. Since the KTF region is strongly influenced by transported ozone, it is important to accurately predict ozone formed outside of the KTF region. *(High priority)*
- Review ozone precursor emissions and estimate ozone impacts from the new Panda Temple Power Generating Station, which is located in Bell County approximately 8 miles southeast of the Temple Georgia ozone monitor. Because the Panda Temple Station was not yet operating in 2012, its impacts on KTF Area ozone were not evaluated in this study. *(High priority)*

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APPENDIX A

KTF Area Off-Road and Area Source Emissions

Appendix A. KTF Area Off-road and Area Source Emissions

Table A-1. 2012 KTF Area off-road and area source NOx emissions (tons per ozone season day).

Source Category	Bell	Coryell	Hamilton	Lampasas	Milam	Mills	San Saba
Off-road							
Agricultural Equipment	1.887	1.243	1.204	0.472	1.854	0.726	0.518
Aircraft	0.140	0.000	0.001	0.001	0.000	0.000	0.000
Commercial Equipment	0.105	0.008	0.010	0.007	0.015	0.005	0.013
Construction and Mining Eq.	1.024	0.160	0.044	0.284	0.212	0.025	0.051
Drilling Equipment	-	-	-	-	0.061	-	-
Industrial Equipment	0.264	0.033	0.007	0.014	0.057	0.004	0.003
Lawn and Garden Equipment	0.091	0.017	0.003	0.008	0.008	0.002	0.002
Locomotives	1.881	0.123	-	0.570	2.040	0.403	0.078
Pleasure Craft	0.142	-	-	-	-	-	-
Railroad Equipment	0.013	0.002	-	0.004	0.007	0.002	-
Recreational Equipment	0.028	0.001	0.001	0.007	0.001	0.001	-
Grand Total	**5.575**	**1.588**	**1.269**	**1.366**	**4.257**	**1.168**	**0.665**
Area							
Fuel Combustion	0.691	0.142	0.035	0.065	0.115	0.021	0.022
Oil and Gas	-	-	0.011	0.003	0.909	0.000	-
Open Burning	0.032	0.025	0.017	0.013	0.041	0.010	0.010
Structural Fires	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Vehicle Fires	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Waste Disposal	-	-	0.004	0.011	0.011	0.004	0.003
Grand Total	**0.724**	**0.167**	**0.068**	**0.092**	**1.077**	**0.035**	**0.034**

Table A-2. 2012 KTF Area off-road and area source VOC emissions (tons per ozone season day).

Source Category	Bell	Coryell	Hamilton	Lampasas	Milam	Mills	San Saba
Off-road							
Agricultural Equipment	0.206	0.136	0.124	0.046	0.203	0.073	0.054
Aircraft	0.064	0.001	0.001	0.001	0.001	0.000	0.000
Commercial Equipment	0.154	0.012	0.015	0.010	0.022	0.008	0.019
Construction and Mining Eq.	0.195	0.025	0.006	0.028	0.029	0.004	0.007
Drilling Equipment	-	-	-	-	0.003	-	-
Industrial Equipment	0.052	0.005	0.001	0.002	0.012	0.001	0.000
Lawn and Garden Equipment	0.787	0.162	0.032	0.067	0.074	0.021	0.022
Locomotives	0.109	0.007	-	0.032	0.114	0.022	0.003
Pleasure Craft	1.599	-	-	-	-	-	-
Railroad Equipment	0.003	0.001	-	0.001	0.001	0.000	-
Recreational Equipment	1.108	0.003	0.003	0.281	0.005	0.003	-
Grand Total	**4.276**	**0.351**	**0.182**	**0.468**	**0.465**	**0.132**	**0.106**
Area							
Architectural Coatings	0.819	0.198	0.022	0.052	0.064	0.013	0.016
Auto Body Refinishing	0.070	0.004	0.001	0.006	0.002	0.002	0.000
Comm. Cooking - Charbroiling	0.025	0.006	0.001	0.001	0.002	0.000	0.000
Comm. Cooking - Frying	0.009	0.002	0.000	0.001	0.001	0.000	0.000
Consumer Products	3.642	0.881	0.097	0.229	0.284	0.056	0.069
Cutback Asphalt	0.248	0.046	0.005	0.019	0.026	0.007	0.005
Degreasing	0.318	0.040	0.006	0.017	0.022	0.006	0.004
Dry Cleaning	0.002	0.000	0.000	0.000	0.000	0.000	-
Fuel Combustion	0.310	0.064	0.011	0.021	0.030	0.006	0.007
Gasoline Distribution	3.372	0.518	0.269	0.352	0.503	0.138	0.196
Gasoline Service Stations	0.249	0.038	0.014	0.028	0.035	0.002	0.014
Graphic Arts	0.766	0.014	0.016	0.016	0.011	0.017	0.017
Industrial Processes	-	-	0.001	-	-	-	-
Industrial Surface Coating	1.532	0.094	0.478	0.051	0.232	0.014	0.006
Landfills	0.196	0.061	0.006	0.014	0.019	0.004	0.005
Leaks/Spills	0.065	0.026	0.003	0.005	0.008	0.002	0.002
Oil and Gas	-	-	0.045	0.009	12.269	0.007	-
Open Burning	0.112	0.088	0.078	0.053	0.168	0.051	0.034
Pesticides	0.318	0.076	0.038	0.053	0.231	0.029	0.071
Pipeline	0.325	-	0.054	-	0.054	0.054	-
Plastic Products: SIC 308	0.101	0.063	-	-	-	-	-
Portable Fuel Storage	0.151	0.022	0.007	0.012	0.024	0.003	0.005
Structural Fires	0.007	0.001	0.000	0.000	0.000	0.000	0.000
Textile Products: SIC 22	0.092	-	-	-	-	-	-
Traffic Marking	0.085	0.039	0.018	0.023	0.042	0.020	0.025
Vehicle Fires	0.002	0.001	0.000	0.000	0.000	0.000	0.000
Waste Disposal	-	-	0.006	0.016	0.017	0.006	0.004
Wastewater Treatment	0.017	0.004	0.001	0.001	0.001	0.000	0.000
Wildfire	0.000	-	-	-	-	-	-
Grand Total	**12.831**	**2.286**	**1.177**	**0.978**	**14.045**	**0.438**	**0.481**

Table A-3. 2012 KTF Area off-road and area source CO emissions (tons per ozone season day).

Source Category	Bell	Coryell	Hamilton	Lampasas	Milam	Mills	San Saba
Off-road							
Agricultural Equipment	2.102	1.312	1.153	0.406	1.965	0.670	0.525
Aircraft	1.011	0.038	0.042	0.046	0.032	0.004	0.015
Commercial Equipment	3.604	0.277	0.327	0.226	0.527	0.175	0.426
Construction and Mining Eq.	2.103	0.202	0.041	0.168	0.207	0.028	0.040
Drilling Equipment	-	-	-	-	0.012	-	-
Industrial Equipment	1.128	0.083	0.028	0.049	0.285	0.014	0.007
Lawn and Garden Equipment	10.400	2.186	0.412	0.840	1.033	0.267	0.290
Locomotives	0.337	0.024	-	0.107	0.407	0.080	0.008
Pleasure Craft	5.116	-	-	-	-	-	-
Railroad Equipment	0.011	0.002	-	0.003	0.006	0.002	-
Recreational Equipment	4.144	0.119	0.118	1.031	0.236	0.118	-
Grand Total	**29.955**	**4.243**	**2.122**	**2.876**	**4.711**	**1.356**	**1.312**
Area							
Comm. Cooking - Charbroiling	0.084	0.020	0.002	0.005	0.006	0.001	0.002
Comm. Cooking - Frying	0.006	0.001	0.000	0.000	0.000	0.000	0.000
Fuel Combustion	1.913	0.382	0.066	0.135	0.204	0.038	0.043
Oil and Gas	-	-	0.007	0.002	1.186	0.000	-
Open Burning	0.830	0.646	0.534	0.428	1.348	0.343	0.252
Structural Fires	0.035	0.008	0.001	0.002	0.002	0.000	0.001
Vehicle Fires	0.007	0.002	0.000	0.001	0.001	0.000	0.000
Waste Disposal	-	-	0.062	0.156	0.162	0.059	0.042
Wildfire	0.009	0.003	-	-	-	-	-
Grand Total	**2.884**	**1.063**	**0.671**	**0.729**	**2.909**	**0.443**	**0.338**

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APPENDIX B

KTF Area Point Source Emissions

Appendix B. KTF Area Point Source Emissions

Table B-1.TCEQ 2012 KTF Area NOx, VOC, and CO point source emissions (tons per ozone season day).

Facility	SIC	County	NOx Emissions (tons per ozone season day)	VOC Emissions (tons per ozone season day)	CO Emissions (tons per ozone season day)
Temple Plant	3086	Bell	0.006	0.685	0.001
Troy Fiberglass Plant	1541	Bell	-	0.280	-
ECS Facility	9999	Bell	-	0.280	-
Sandow Generating Station	4911	Milam	8.901	0.239	71.317
Belco Manufacturing Company	2221	Bell	-	0.204	-
Cushioning Manufacturing	3086	Bell	0.008	0.165	0.007
Temple North Laminate Facility	3089	Bell	0.164	0.163	0.458
Fort Hood	9711	Bell	0.079	0.147	0.201
Nolanville Plant	3296	Bell	0.017	0.032	1.945
Fiberglass Spray Facility	5075	Bell	-	0.031	-
Rockdale Operations	3334	Milam	0.028	0.009	0.023
Total			**9.203**	**2.236**	**73.953**

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APPENDIX C

Temple Georgia Monitor Wind Roses

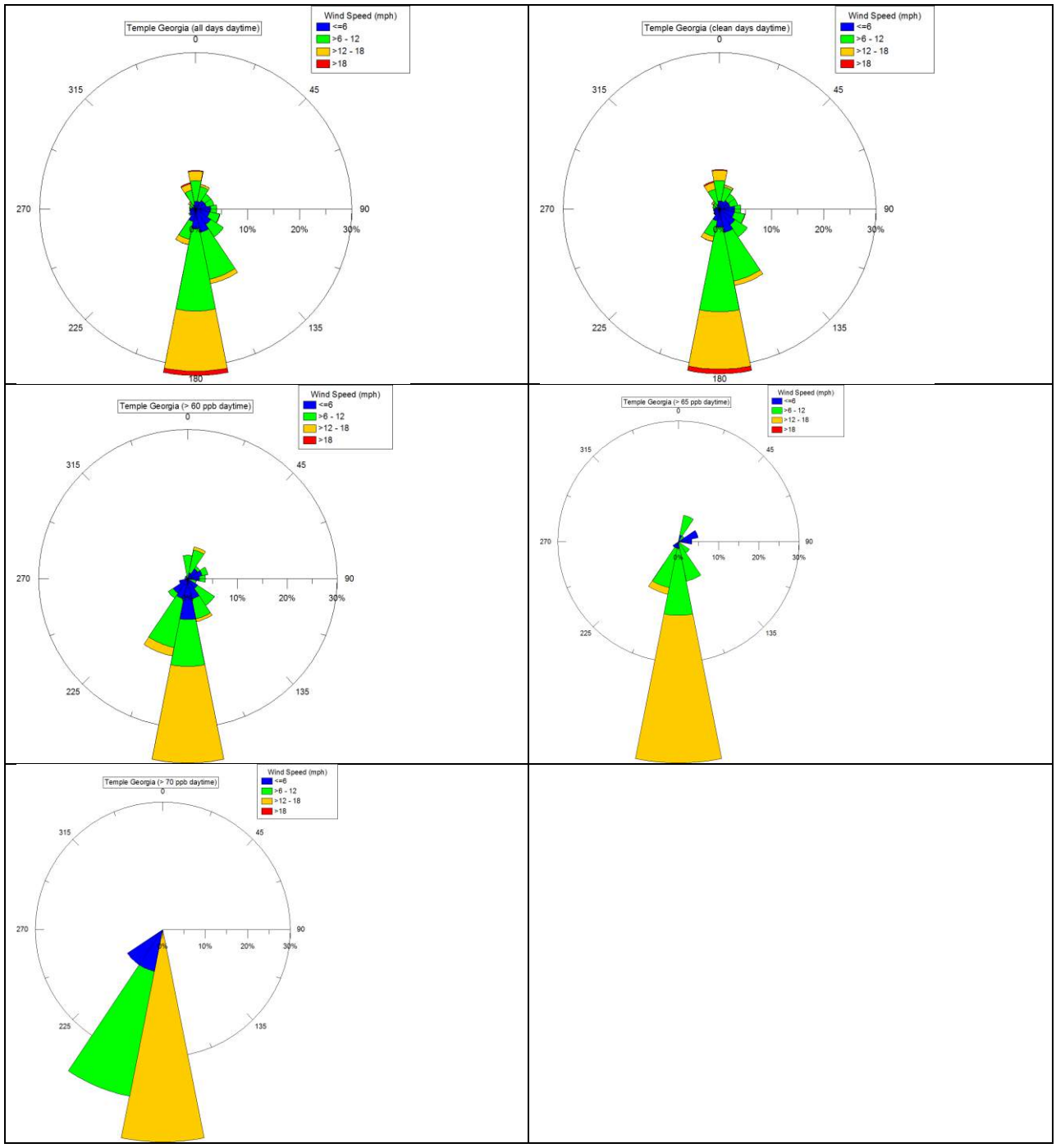

Figure C-1. Temple Georgia wind rose diagrams for daytime hours (8 am- 6 pm), for different MDA8 ozone thresholds. 2014 only. Upper left: all ozone season days; upper right: days with MDA8 ≤ 60 ppb; center left: days with MDA8 > 60 ppb; center right: days with MDA8 > 65 ppb; lower left: days with MDA8 > 70 ppb (1 day only); lower right: no days with MDA8 > 75 ppb.

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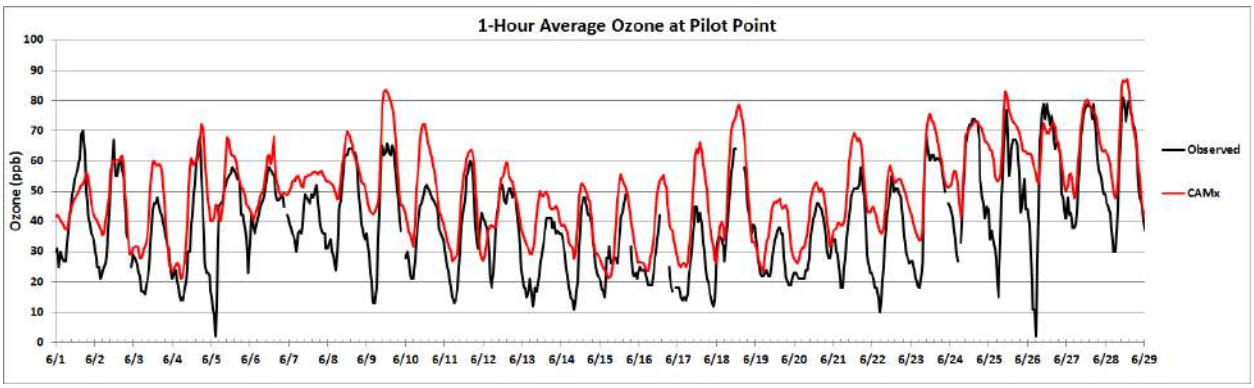
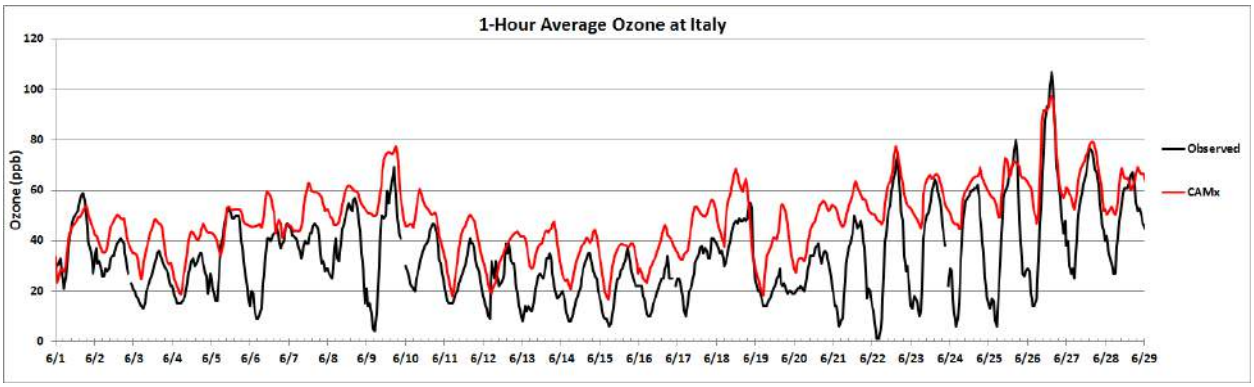
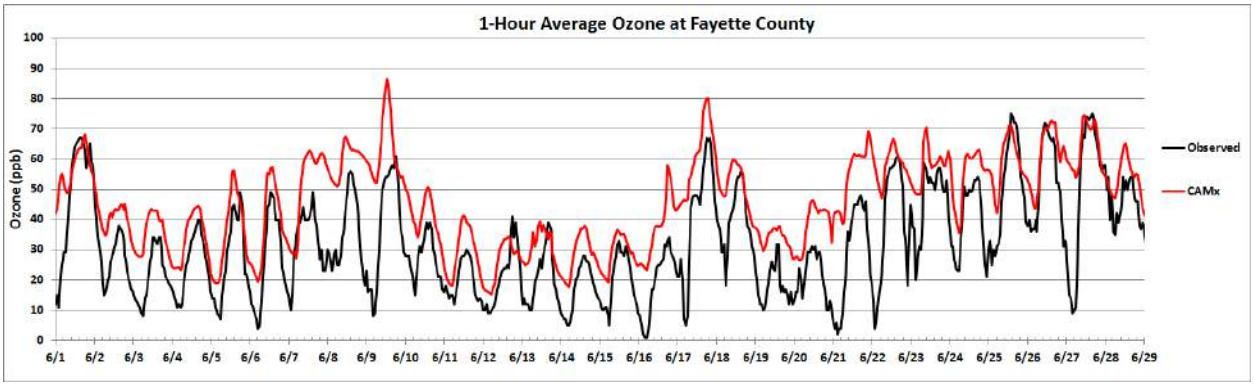
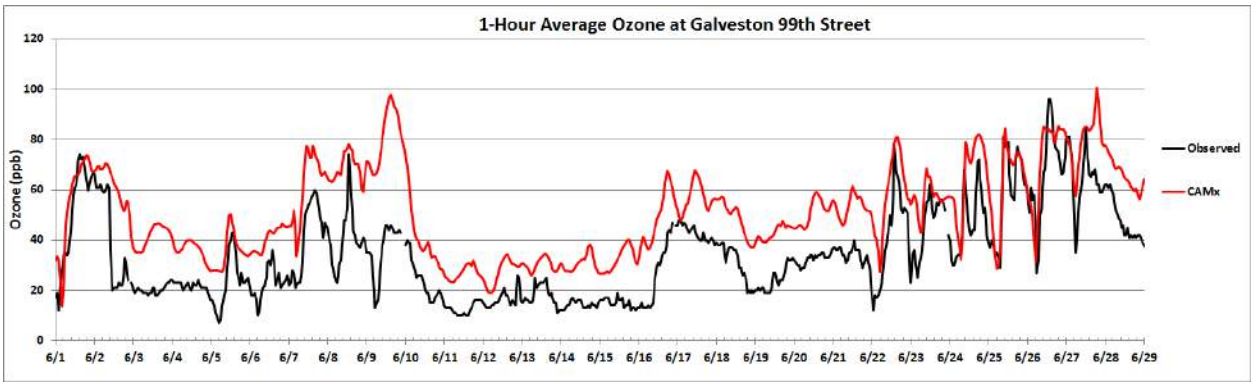
APPENDIX D

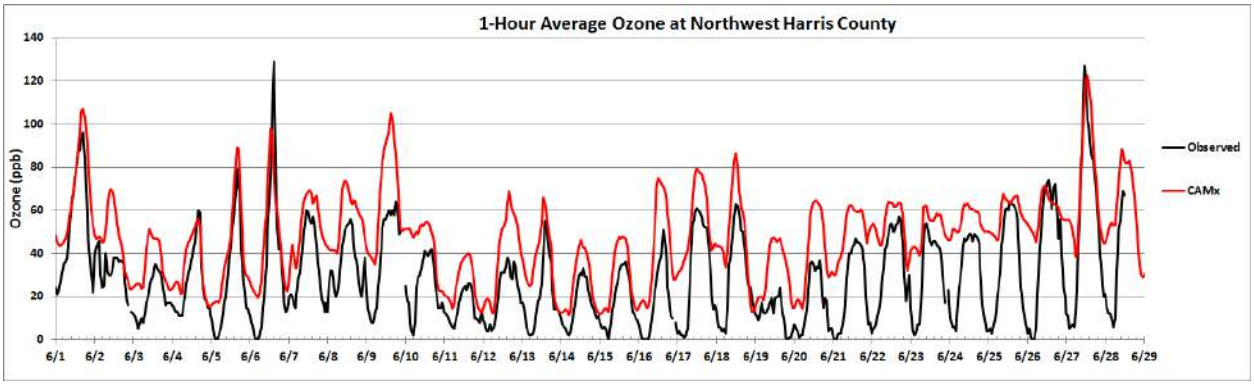
Ozone Model Performance Evaluation at Selected Texas Monitors

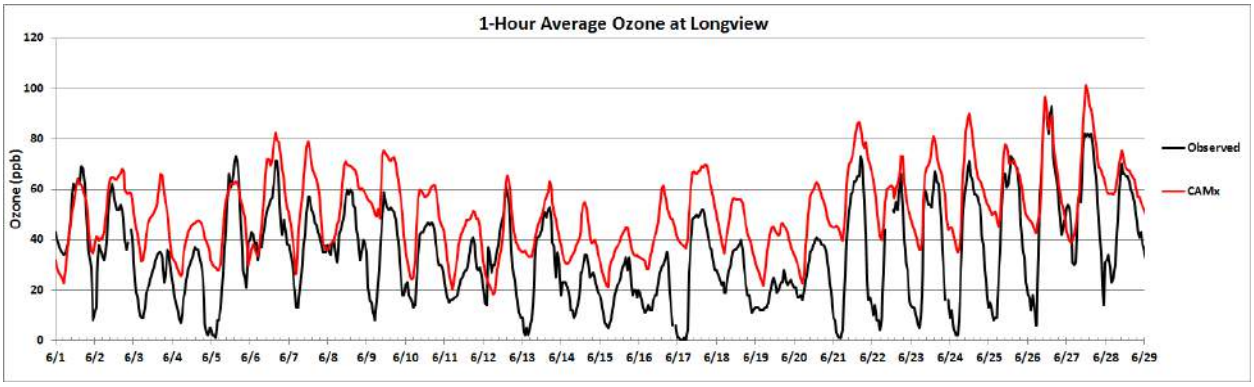

1-Hour Average Ozone at Pilot Point
Ozone (ppb)
Observed
CAMx

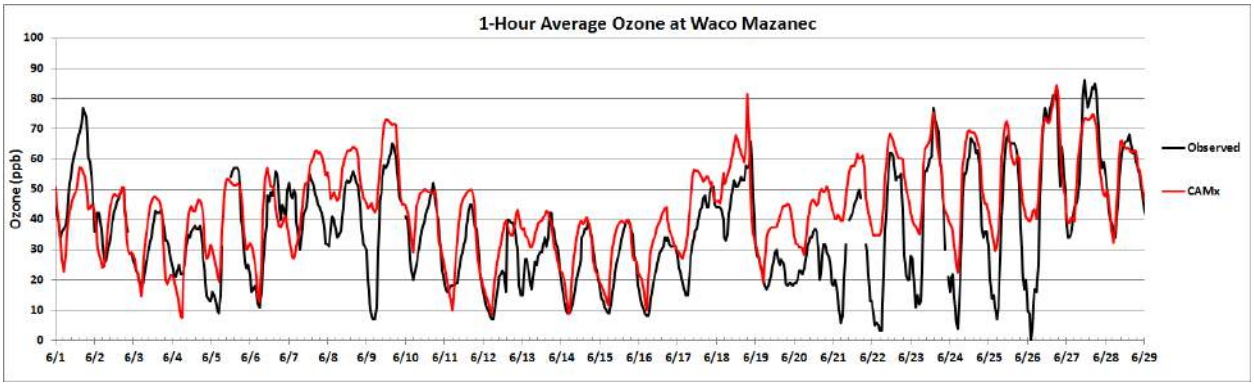

1-Hour Average Ozone at Italy
Ozone (ppb)
Observed
CAMx

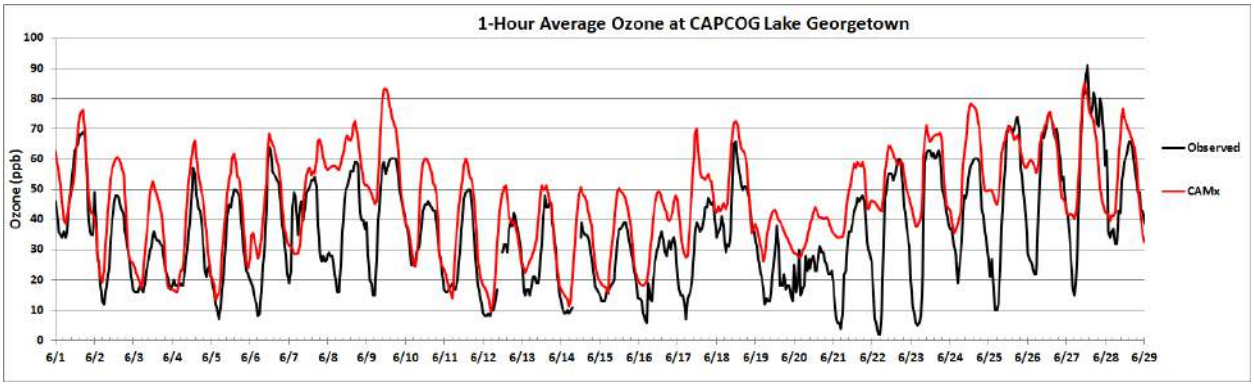

1-Hour Average Ozone at Fayette County
Ozone (ppb)
Observed
CAMx

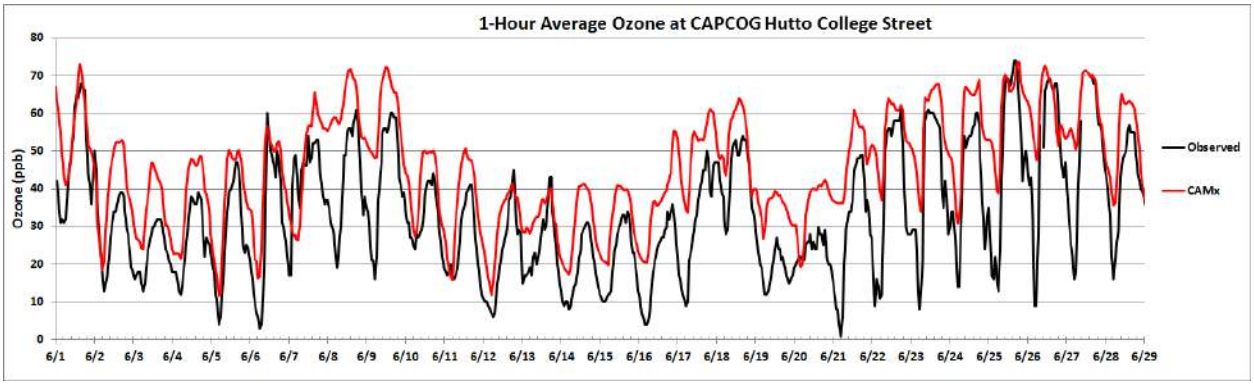

1-Hour Average Ozone at Galveston 99th Street
Ozone (ppb)
Observed
CAMx

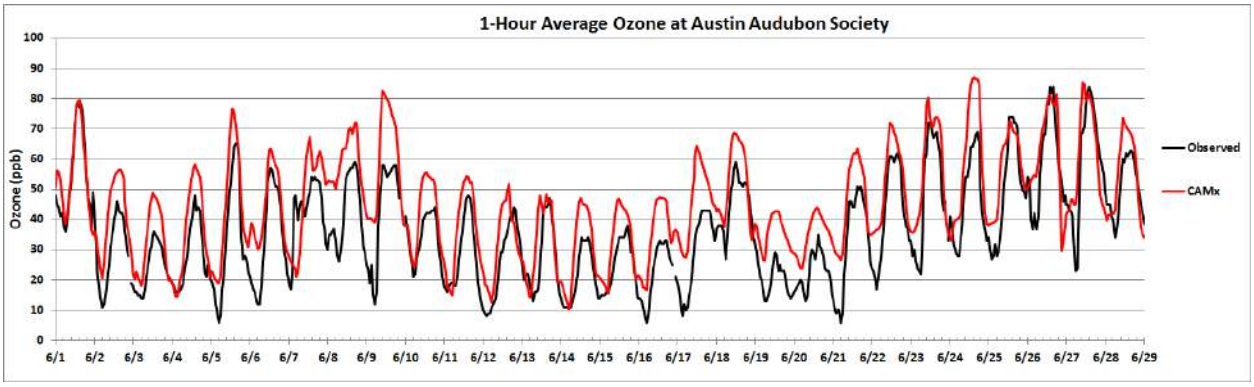

1-Hour Average Ozone at Northwest Harris County
Ozone (ppb)
Observed
CAMx

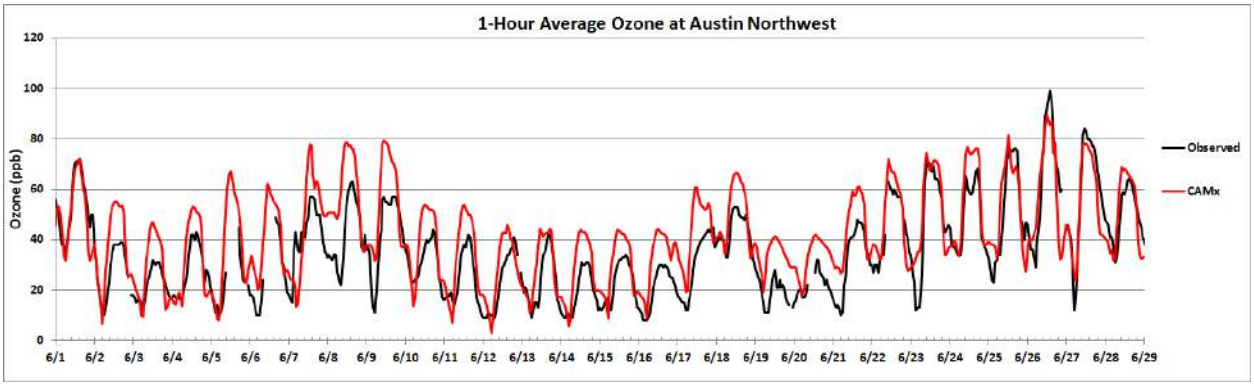

1-Hour Average Ozone at Longview
Ozone (ppb)
Observed
CAMx

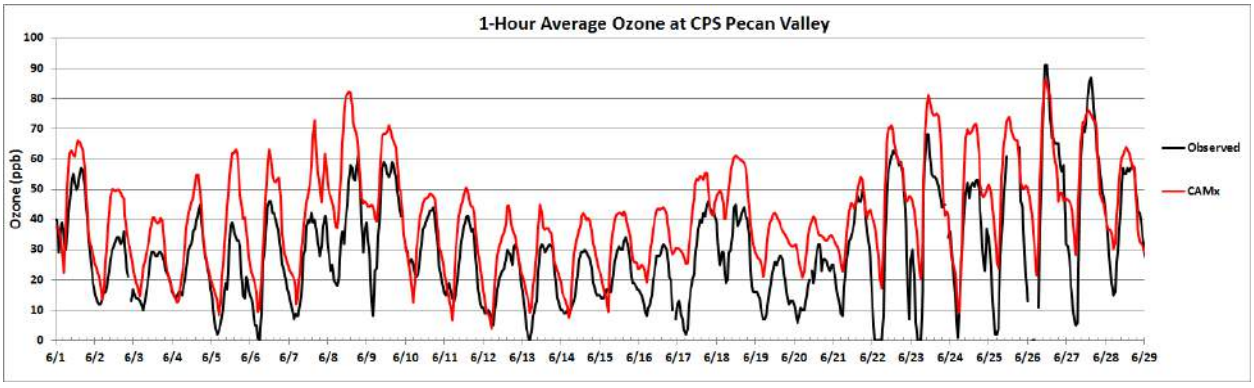

1-Hour Average Ozone at Waco Mazanec
Ozone (ppb)
Observed
CAMx


1-Hour Average Ozone at CAPCOG Lake Georgetown
Ozone (ppb)
Observed
CAMx


1-Hour Average Ozone at CAPCOG Hutto College Street
Ozone (ppb)
Observed
CAMx


1-Hour Average Ozone at Austin Audubon Society
Ozone (ppb)
Observed
CAMx


1-Hour Average Ozone at Austin Northwest
Ozone (ppb)
Observed
CAMx


1-Hour Average Ozone at CPS Pecan Valley
Ozone (ppb)
Observed
CAMx