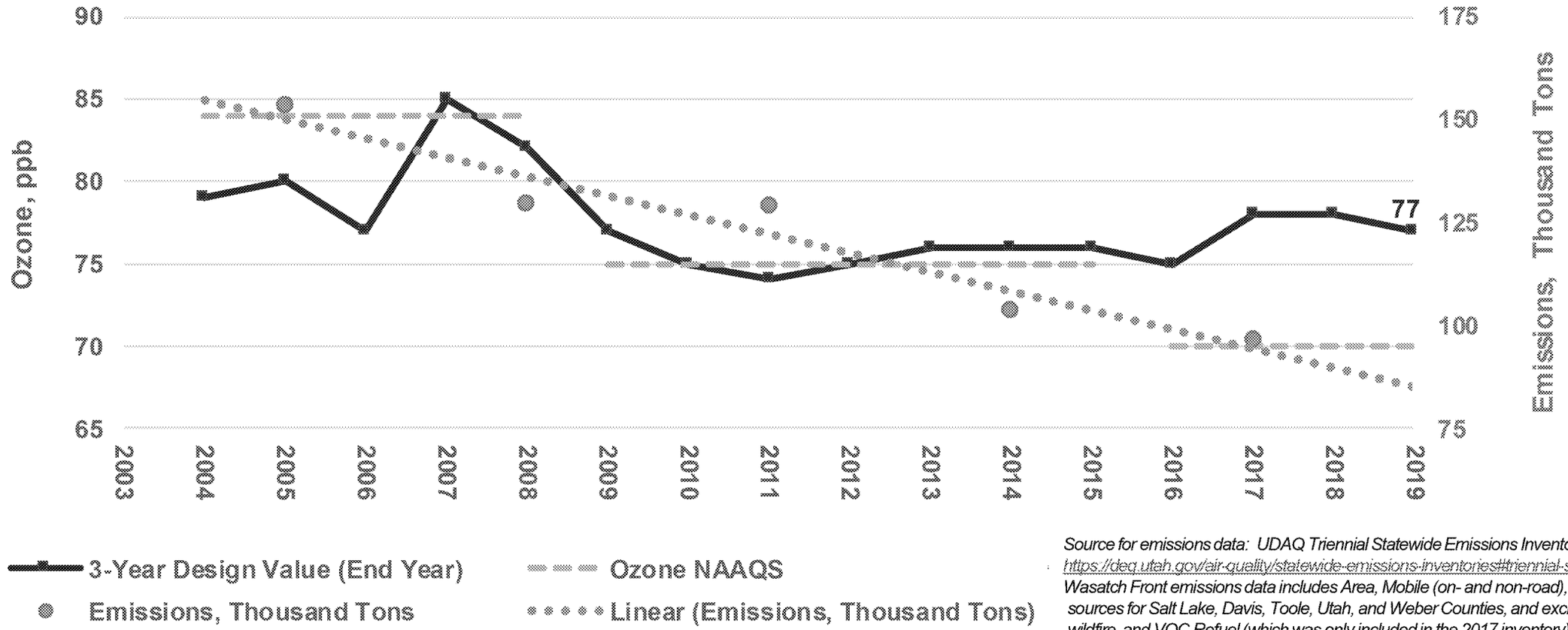
# Wasatch Front: Ozone Design Values and Precursor Emissions Trends




*Source for emissions data: UDAQ Triennial Statewide Emissions Inventories at https://deq.utah.gov/air-quality/statewide-emissions-inventories#triennial-statewide*
*Wasatch Front emissions data includes Area, Mobile (on- and non-road), and Point sources for Salt Lake, Davis, Toole, Utah, and Weber Counties, and excludes biogenic, wildfire, and VOC Refuel (which was only included in the 2017 inventory) emissions.*

**37% Reduction in Wasatch Front NOx + VOC**
**Without Corresponding Ozone Design Value Improvement**

# Modeling International Ozone Contribution to Wasatch Front Nonattainment Areas

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**Ramboll Air Sciences Group, Novato CA**

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# Overview
# Approach

- Use EPA's 2016 national modeling platform (MP) for CMAQ & CAMx
  - Several MP versions: "Beta", "Beta Prime", "V1" (related to North American emission updates)
  - In early 2019, EPA conducted a model performance evaluation for Beta CMAQ & CAMx
- Address 2 key elements in EPA's draft §179B guidance
  - Model-scaled Design Values (DVs) according to EPA's SIP modeling guidance
    - Based on EPA's 2019 run of Beta CMAQ for BASE and ZROW scenarios
    - Reviewed EPA's CMAQ model performance evaluation at Wasatch monitoring sites
  - Ozone Source Apportionment (OSAT) modeling
    - Based on Ramboll's 2020 run of V1 CAMx BASE scenario
    - Conducted CAMx model performance evaluation at Wasatch monitoring sites
    - Tracked three source regions (International, US and Utah) and two sectors (anthropogenic, natural)



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# Overview
# Results – Model Performance Evaluation

- June-September MDA8 ozone at 9 Wasatch Monitoring sites
  - Beta CMAQ & V1 CAMx performance is generally good & within benchmarks
  - At levels typically achieved for SIP modeling
  - Consistent under prediction, performance slightly degrades on days >60 ppb
- Is systematic under prediction an issue?
  - May affect relative contribution from international transport in DV scaling
  - Well-simulated US Background + US Regional ozone at Gothic site in Colorado (remote, high altitude)
  - Evidence points to lack of local ozone production
    - ➢ International contribution in DV scaling may be over estimated, but by <2 ppb

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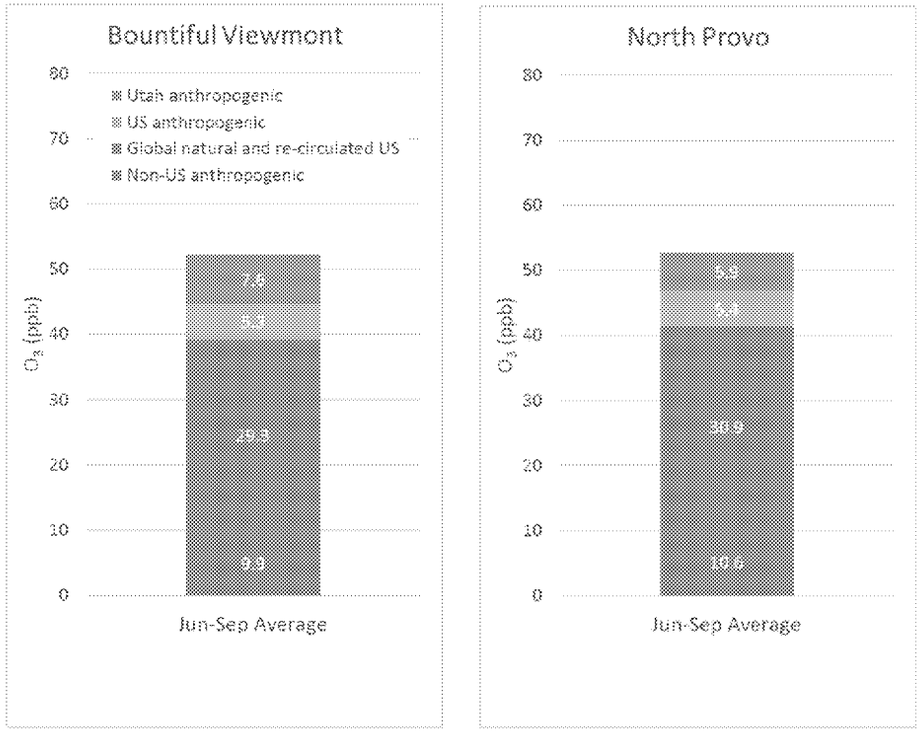
# Overview
# Results –International Anthropogenic Emissions (IAE)

- DV scaling results
  - Beta CMAQ ZROW:BASE results in DV<70.9 ppb at all sites (by 1.3 - 9.0 ppb)
  - V1 CAMx OSAT DV results in DV<<70.9 ppb at all sites (by 5.8 - 12.6 ppb)
- Absolute modeled IAE contributions
  - Bountiful has highest DV (78 ppb 2016-2018)
  - Needs largest IAE contribution: 7.1 ppb (RRF = 0.9090)
  - CMAQ & CAMx IAE contribution range: 6.7 – 9.9 ppb
- CMAQ & CAMx results bracket the needed DV reduction

June-September Average OSAT



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# Beta CMAQ ZROW Modeling

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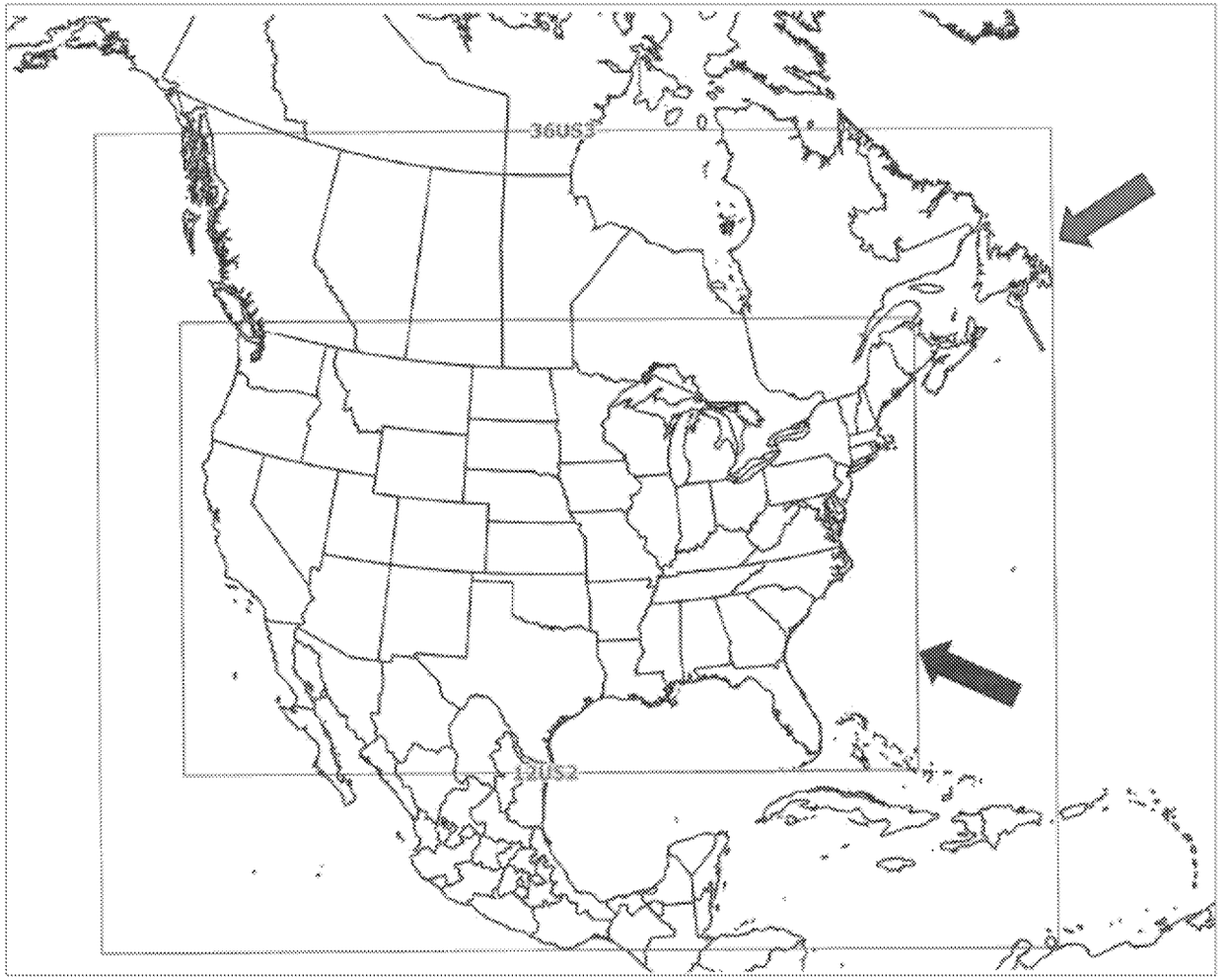
# EPA 2016 Modeling Platform (MP)

- Two nested modeling grids:
  - 36-km (North America – NA)
  - 12-km (Continental US – CONUS)
- 2016 "BASE" scenario emissions:
  - Anthropogenic global from several providers (EDGAR/HTAP/CEDS, Asia, etc.)
  - North America: US, Canada, Mexico
  - Natural: biogenic, lightning NOx, fires, oceanic
- "Zero Rest of World" (ZROW) scenario removes all non-US anthropogenic emissions (IAE)
- Hemispheric CMAQ provides global boundary conditions for BASE and ZROW

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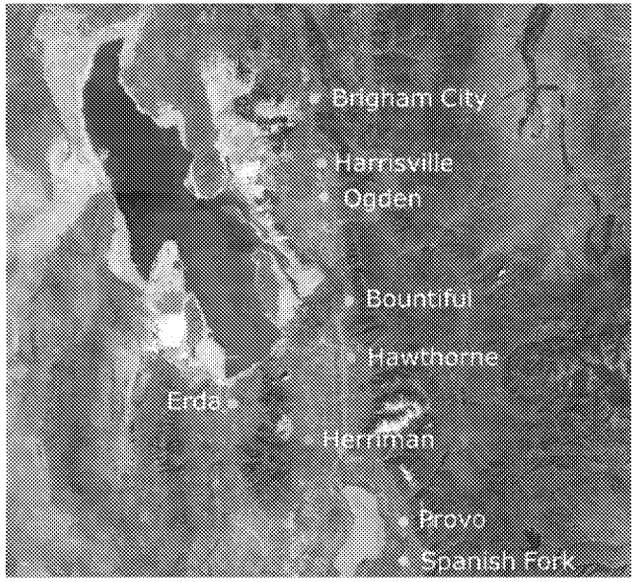
# 2016 Beta CMAQ Ozone Model Performance Evaluation Reported by EPA in 2019

- MDA8 ozone over June-August at 9 sites
- CMAQ performance is generally good & within benchmarks for acceptable performance
  - At levels typically achieved for SIP modeling
  - Consistent under prediction, performance degrades on days >60 ppb
- Is systematic under prediction an issue?
  - May affect relative DV contribution from IAE
  - We looked at high-altitude "Gothic" CASTNET site in Colorado Rockies
  - Very good model-monitor agreement: suggests US Background and US regional ozone are well simulated




| MDA8 Ozone | Correlation | Bias | Error |
|---|---|---|---|
| All summer days | 0.63 | -7% | 11% |
| Days > 60 ppb | 0.34 | -13% | 14% |
| Benchmark* | >0.50 | <±15% | <25% |

*Emery, C., Z. Liu, A.G. Russell, M.T. Odman, G. Yarwood, N. Kumar (2016): Recommendations on statistics and benchmarks to assess photochemical model performance, J. Air & Waste Management Association, http://dx.doi.org/10.1080/10962247.2016.1265027

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# SMAT DV Scaling Using EPA Beta CMAQ BASE and ZROW Output

- Develop ZROW model-scaled DVs for each site in the Wasatch Front area
  - Scale local DVs by average relative model changes over high modeled ozone days (>60 ppb)
  - Allows use of year-specific modeling (2016) to apply to range of recent DV years
  - Model-scaled DVs ≤ 70.9 ppb indicate attaining monitors "but for" IAE
- BASE and ZROW MDA8 ozone concentrations go into EPA's Software for the Modeled Attainment Test (SMAT)
  - Calculates site-specific "relative response factor" (RRF): ratio of average MDA8 ozone (ZROW/BASE) over 10 highest modeled ozone days
  - SMAT applies the RRF as a DV scaling factor:

$$DV_{scaled} = DV_{monitored} \times \underbrace{\left(\frac{\bar{C}_{ZROW}}{\bar{C}_{Base}}\right)}_{\text{RRF}}$$

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# SMAT DV Scaling Using EPA Beta CMAQ BASE and ZROW Output

| Site | County | 2013-2017 Average DV[1]* | Modeled RRF (ZROW/Base) | ZROW DV (≤70.9 Attains) |
|---|---|---|---|---|
| Northern Wasatch Front | | | | |
| 490110004 Bountiful | Davis | 74 | 0.8869 | 66.0 |
| 490353006 Hawthorne | Salt Lake | 76 | 0.8924 | 68.0 |
| 490353013 Herriman | Salt Lake | 76 | 0.8686 | 66.0 |
| 490450004 Erda | Tooele | 73 | 0.8592 | 62.7 |
| 490570002 Ogden | Weber | 72 | 0.8811 | 63.4 |
| 490571003 Harrisville | Weber | 72 | 0.8784 | 63.5 |
| Southern Wasatch Front | | | | |
| 490490002 Provo | Utah | 71 | 0.8881 | 63.6 |
| 490495010 Spanish Fork | Utah | 72 | 0.8905 | 64.1 |

[1] SMAT-CE is delivered with DV data up through 2017; these results are directly from SMAT-CE.

* EPA modeling guidance recommends scaling the 3-year average DV: in this case, 2013-2015, 2014-2016, 2015-2017

| Site | County | 2015-2017 DV[1] | Modeled RRF (ZROW/Base) | ZROW DV (≤70.9 Attains) |
|---|---|---|---|---|
| Northern Wasatch Front | | | | |
| 490110004 Bountiful | Davis | 75 | 0.8869 | 66.5 |
| 490353006 Hawthorne | Salt Lake | 78 | 0.8924 | 69.6 |
| 490353013 Herriman | Salt Lake | 76 | 0.8686 | 66.0 |
| 490450004 Erda | Tooele | 73 | 0.8592 | 62.7 |
| 490570002 Ogden | Weber | 73 | 0.8811 | 64.3 |
| 490571003 Harrisville | Weber | 73 | 0.8784 | 64.1 |
| Southern Wasatch Front | | | | |
| 490490002 Provo | Utah | 72 | 0.8881 | 63.9 |
| 490495010 Spanish Fork | Utah | 71 | 0.8905 | 63.2 |

[1] Using latest DV available in SMAT-CE; these results are directly from SMAT-CE.

| Site | County | 2016-2018 DV[1] | Modeled RRF (ZROW/Base) | ZROW DV (≤70.9 Attains) |
|---|---|---|---|---|
| Northern Wasatch Front | | | | |
| 490110004 Bountiful | Davis | 78 | 0.8869 | 69.2 |
| 490353006 Hawthorne | Salt Lake | 76 | 0.8924 | 67.8 |
| 490353013 Herriman | Salt Lake | 77 | 0.8686 | 66.9 |
| 490450004 Erda | Tooele | 74 | 0.8592 | 63.6 |
| 490570002 Ogden | Weber | 75 | 0.8811 | 66.1 |
| 490571003 Harrisville | Weber | 74 | 0.8784 | 65.0 |
| Southern Wasatch Front | | | | |
| 490490002 Provo | Utah | N/A | 0.8881 | N/A |
| 490495010 Spanish Fork | Utah | 72 | 0.8905 | 64.1 |

[1] Using latest EPA-official DV; these results apply RRF to 2016-2018 DV outside of SMAT-CE.

| Site | County | 2017-2019 DV[1] | Modeled RRF (ZROW/Base) | ZROW DV (≤70.9 Attains) |
|---|---|---|---|---|
| Northern Wasatch Front | | | | |
| 490110004 Bountiful | Davis | 77 | 0.8869 | 68.3 |
| 490353006 Hawthorne | Salt Lake | 76 | 0.8924 | 67.8 |
| 490353013 Herriman | Salt Lake | 75 | 0.8686 | 65.1 |
| 490450004 Erda | Tooele | 72 | 0.8592 | 61.9 |
| 490570002 Ogden | Weber | 71 | 0.8811 | 62.6 |
| 490571003 Harrisville | Weber | 71 | 0.8784 | 62.4 |
| Southern Wasatch Front | | | | |
| 490490002 Provo | Utah | N/A | 0.8881 | N/A |
| 490495010 Spanish Fork | Utah | 70 | 0.8905 | 62.3 |

[1] Using latest EPA-official DV; these results apply RRF to 2017-2019 DV outside of SMAT-CE.

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In every case ZROW results in DV<70 ppb, well within attainment

# V1 CAMx OSAT Modeling

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# 2016 V1 CAMx Ozone Model Performance Evaluation

- CAMx performance is consistent with CMAQ
  - Consistent under prediction, performance degrades on days >60 ppb
- Does systematic under prediction affect DV projection?
  - If caused by IAE: IAE contribution too low, projected DV too high
    - Does not seem to be the case (following slides)
  - If caused by local production: IAE contribution slightly too high, projected DV slightly too low
    - This seems to be the case (following slides)
  - If causes are ~ equivalent: they are mitigated by RRF
  - What about compensating over/under biases?

| Beta CMAQ (June-August) | | | |
|---|---|---|---|
| **MDA8 Ozone** | **Correlation** | **Bias** | **Error** |
| All summer days | 0.63 | -7% | 11% |
| Days > 60 ppb | 0.34 | -13% | 14% |
| Benchmark* | >0.50 | <±15% | <25% |

| V1 CAMx (June-September) | | | |
|---|---|---|---|
| **MDA8 Ozone** | **Correlation** | **Bias** | **Error** |
| All summer days | 0.78 | -6% | 10% |
| Days > 60 ppb | 0.42 | -12% | 13% |
| Benchmark* | >0.50 | <±15% | <25% |

*Emery, C., Z. Liu, A.G. Russell, M.T. Odman, G. Yarwood, N. Kumar (2016): Recommendations on statistics and benchmarks to assess photochemical model performance, J. Air & Waste Management Association, http://dx.doi.org/10.1080/10962247.2016.1265027

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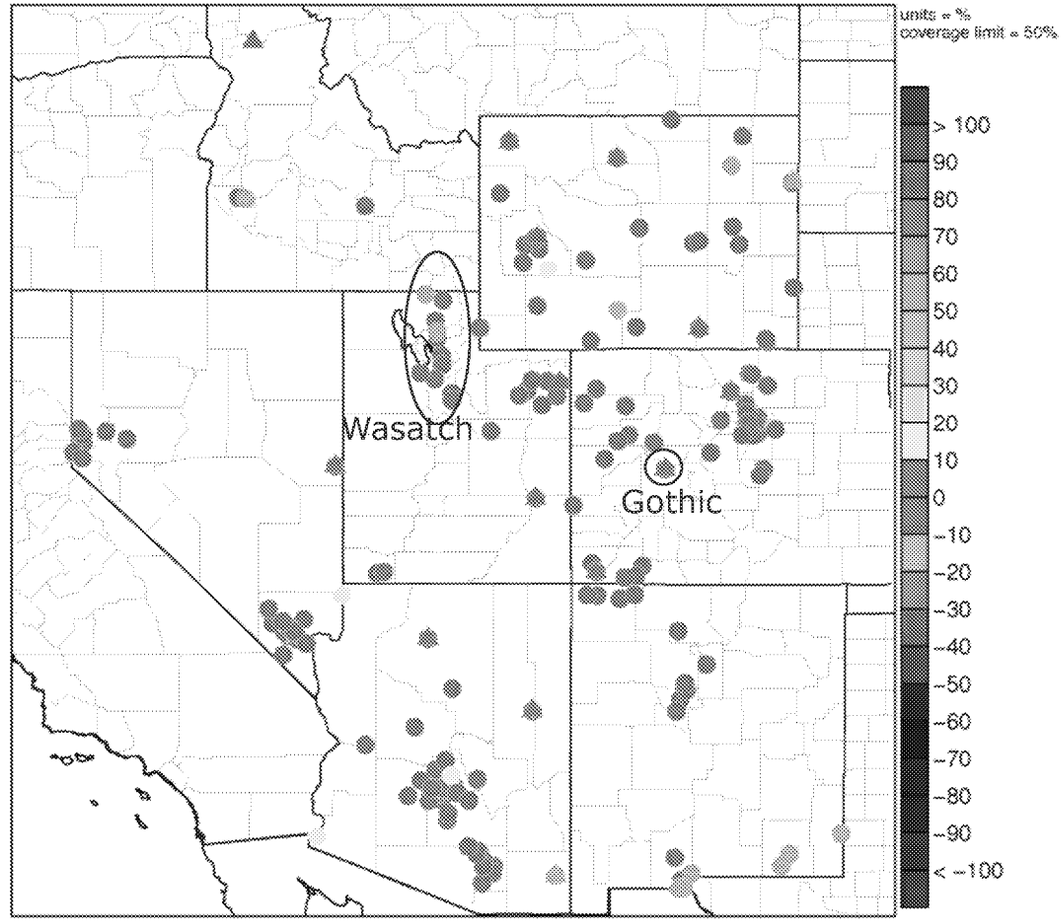
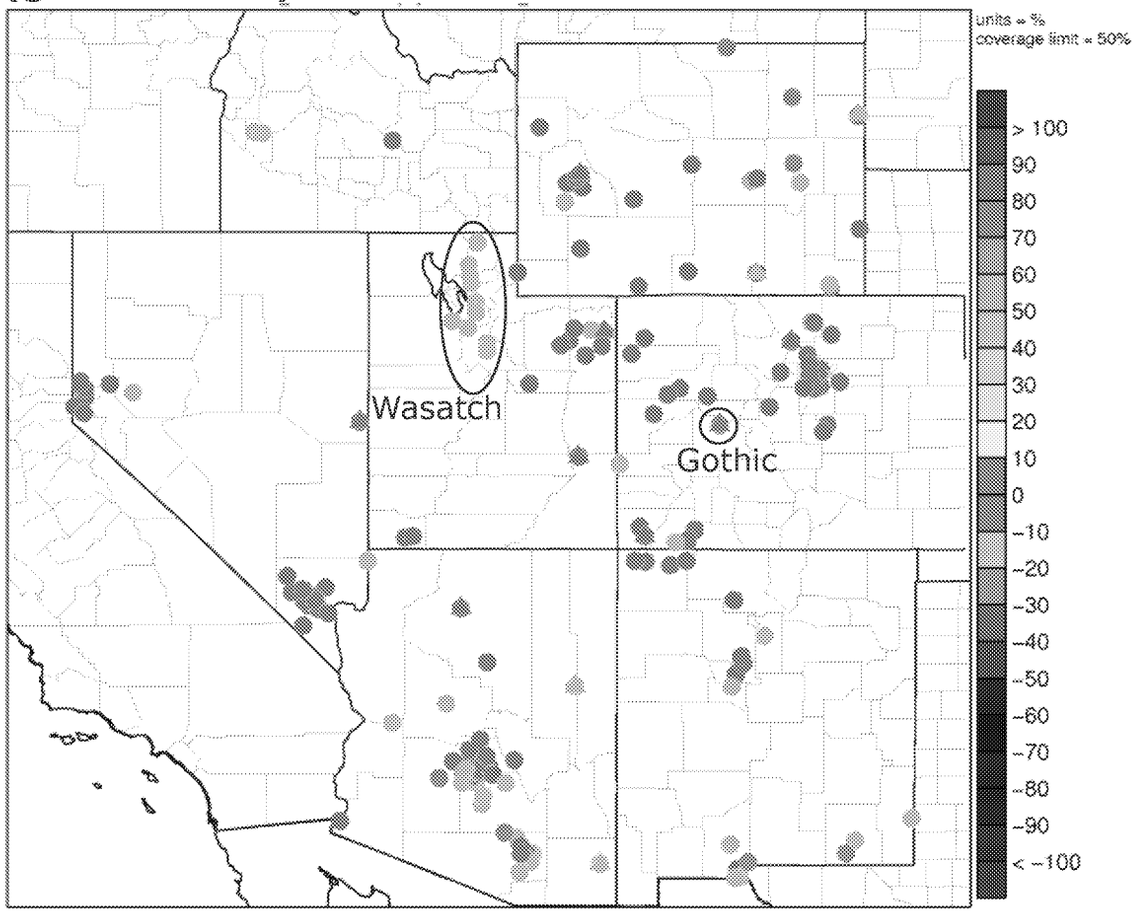
# 2016 V1 CAMx Ozone Model Performance Evaluation
# June-September Normalized Mean Bias (NMB)

NMB for all days: good agreement at most rural and urban sites (grey dots)




CIRCLE=AQS_Daily_O3; TRIANGLE=CASTNET_Daily;

NMB for days > 60 ppb: urban low bias (green dots)

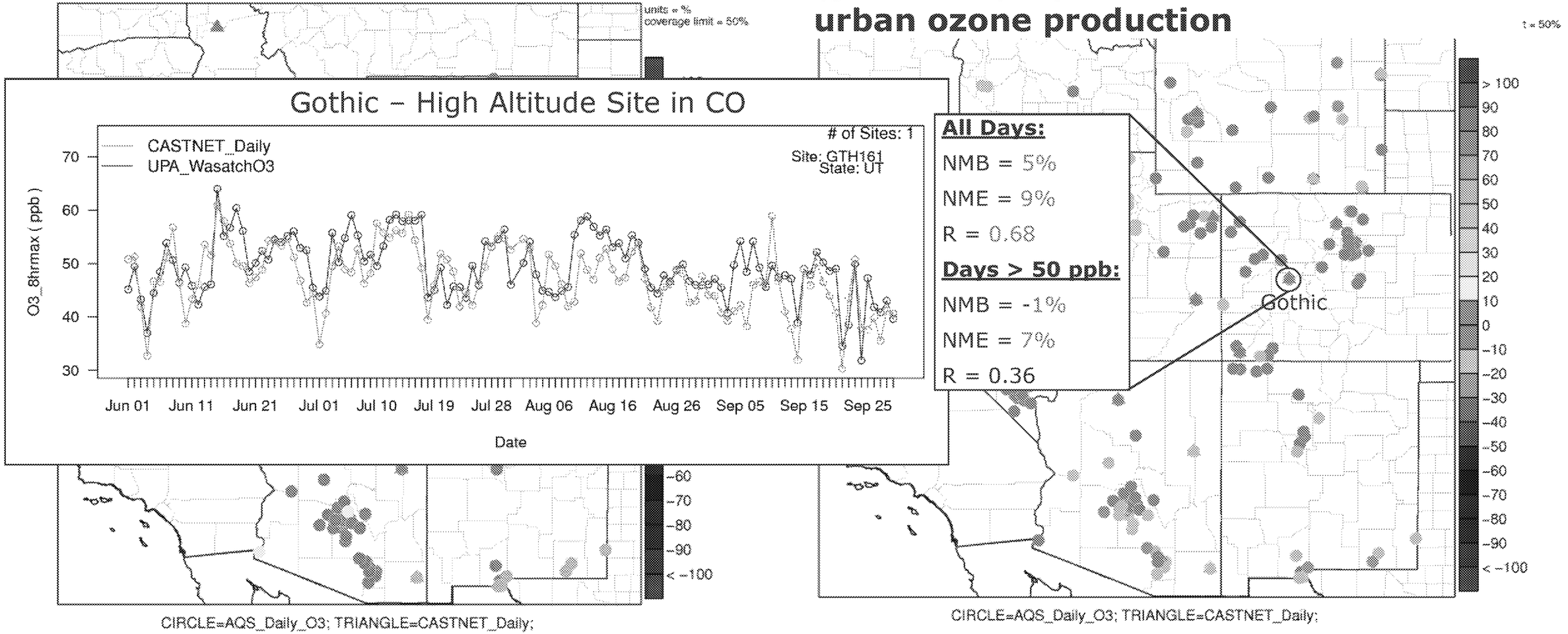



CIRCLE=AQS_Daily_O3; TRIANGLE=CASTNET_Daily;

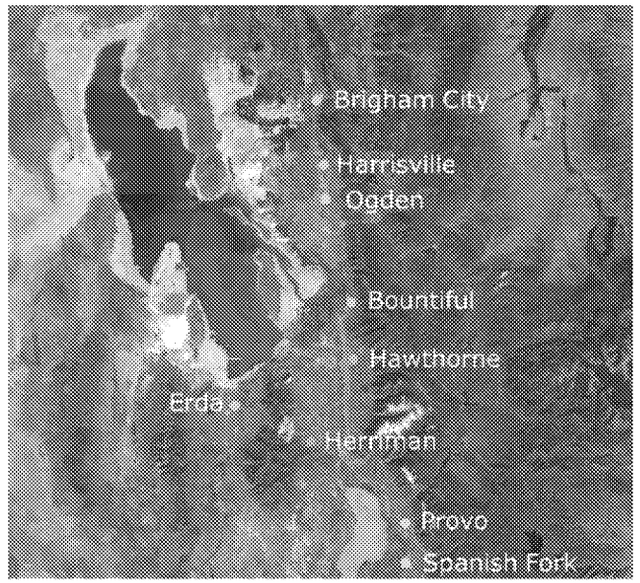
# 2016 V1 CAMx Ozone Model Performance Evaluation
# June-September Normalized Mean Bias (NMB)

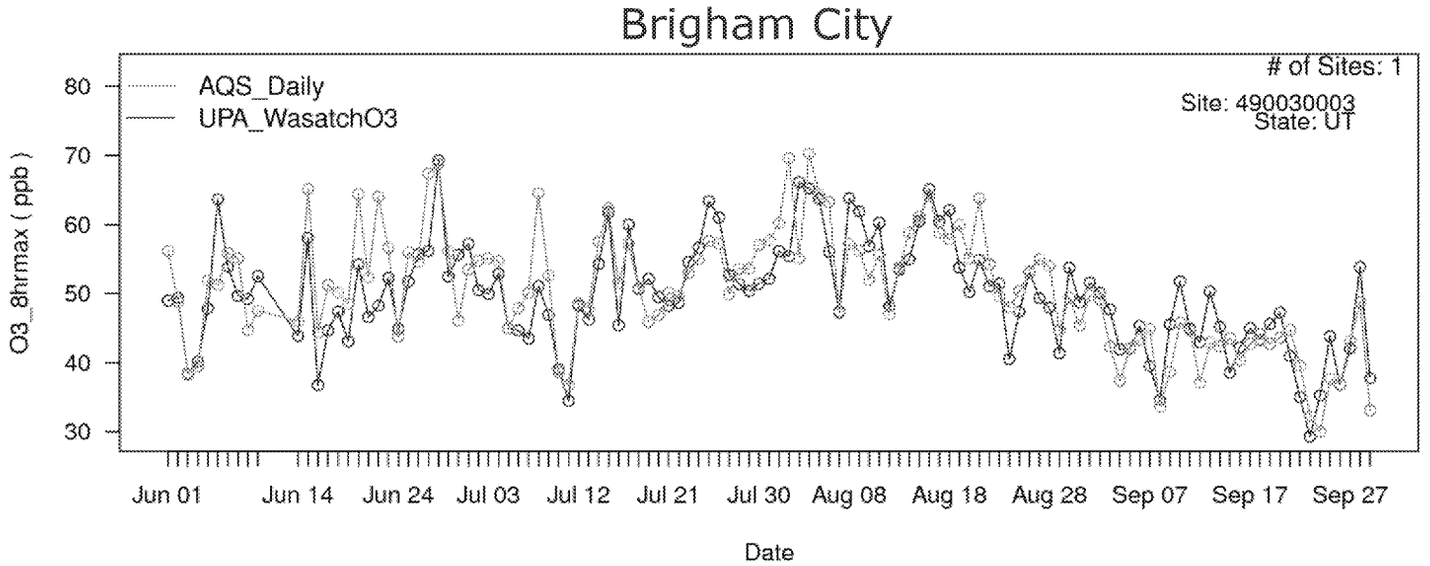
NMB for all days: good agreement at most rural and urban sites (grey dots)

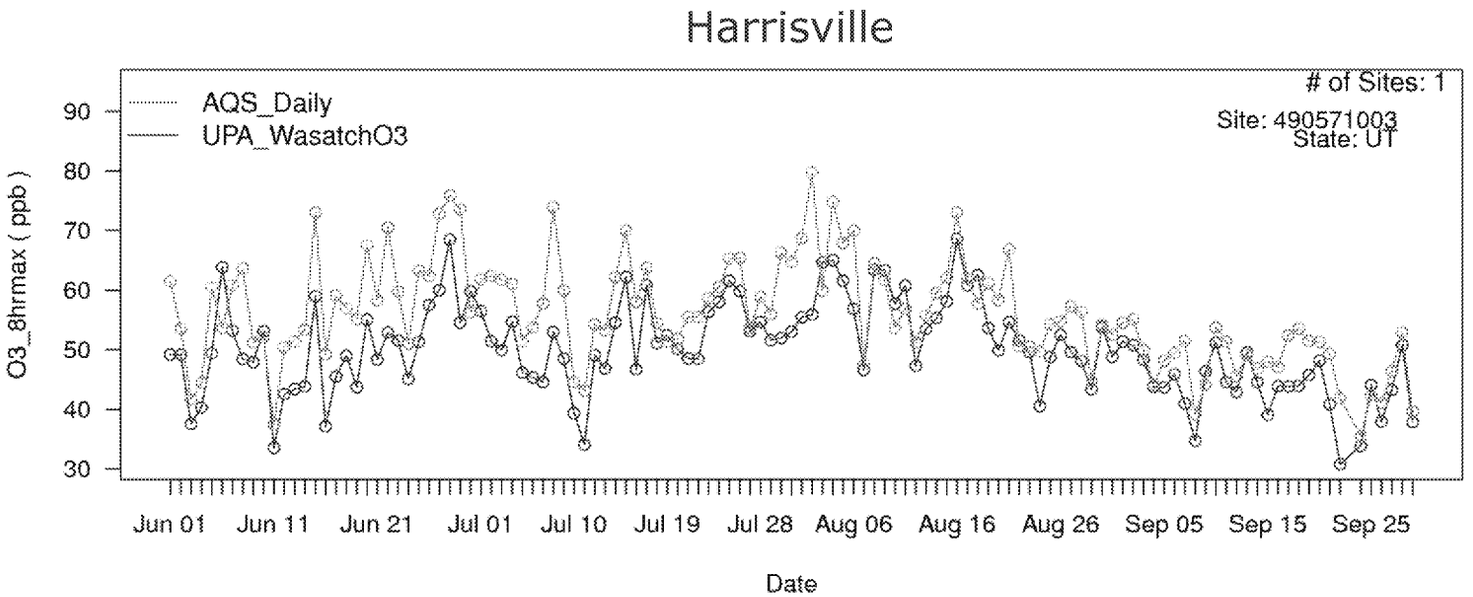
NMB for days > 60 ppb: urban low bias (green dots) – **points to lack of local urban ozone production**



# MDA8 Ozone Time Series

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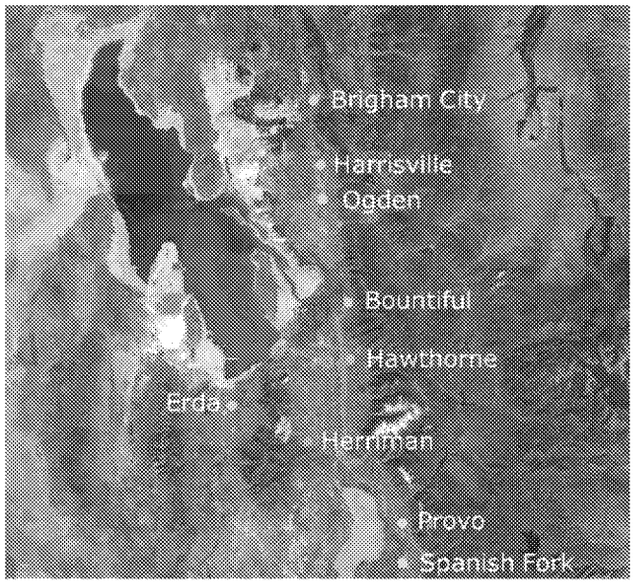
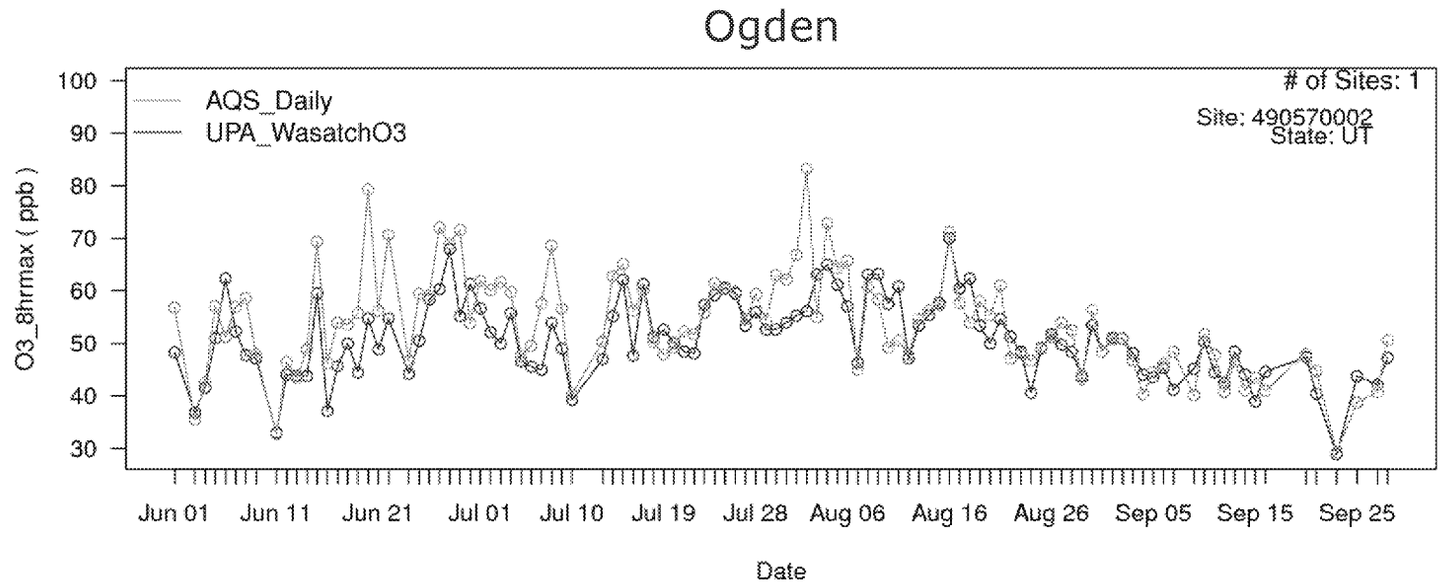
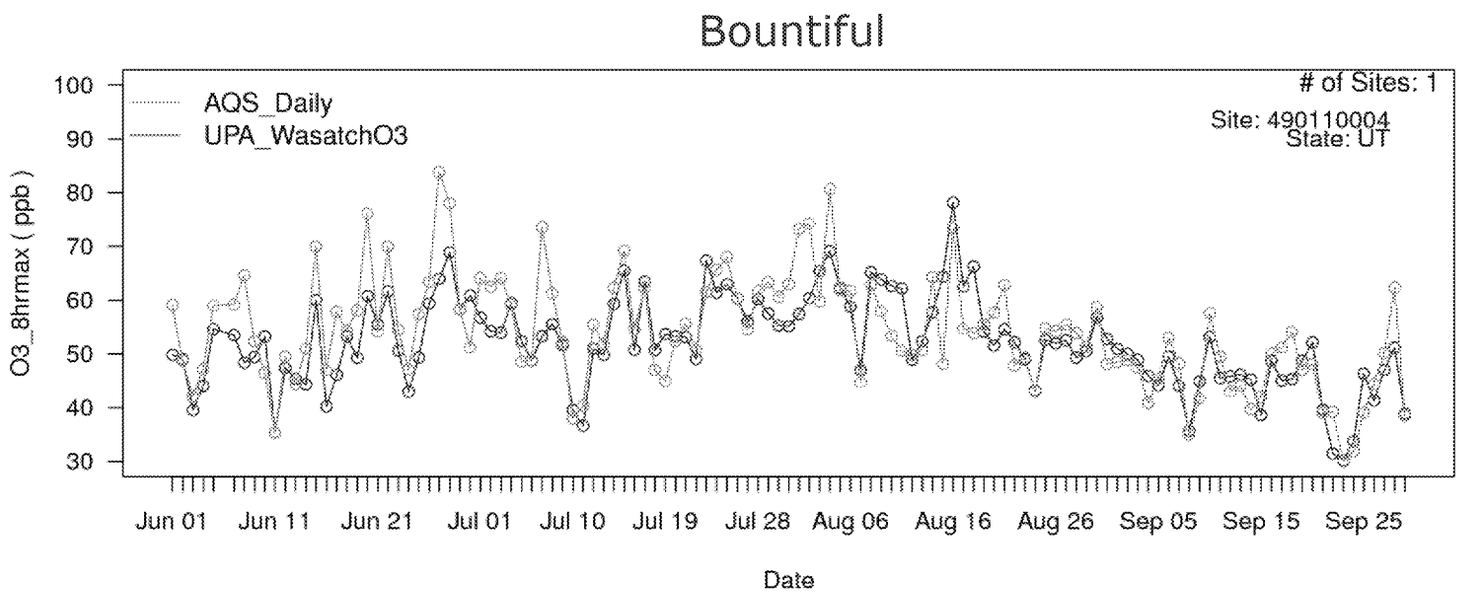
# MDA8 Ozone Time Series

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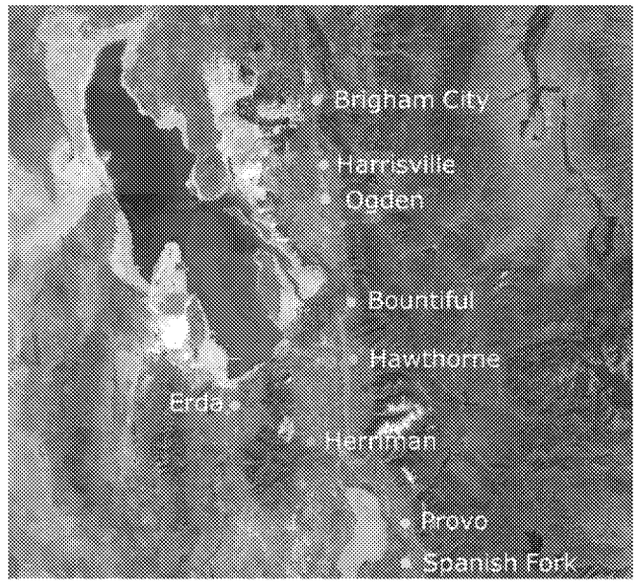


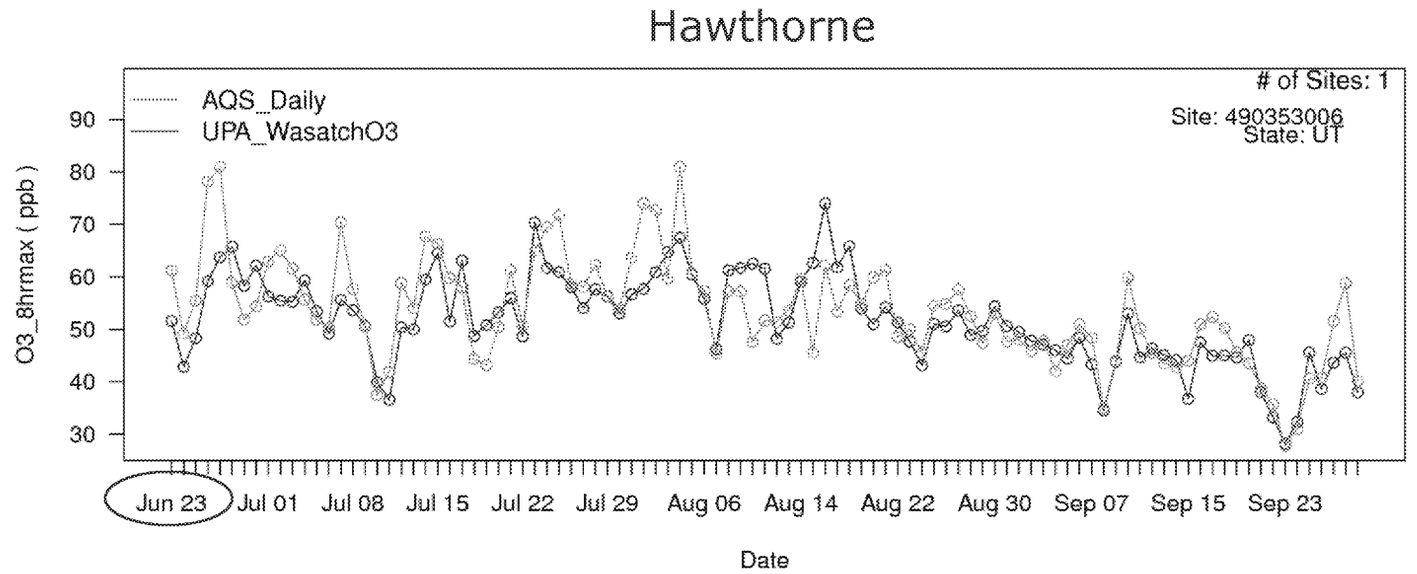


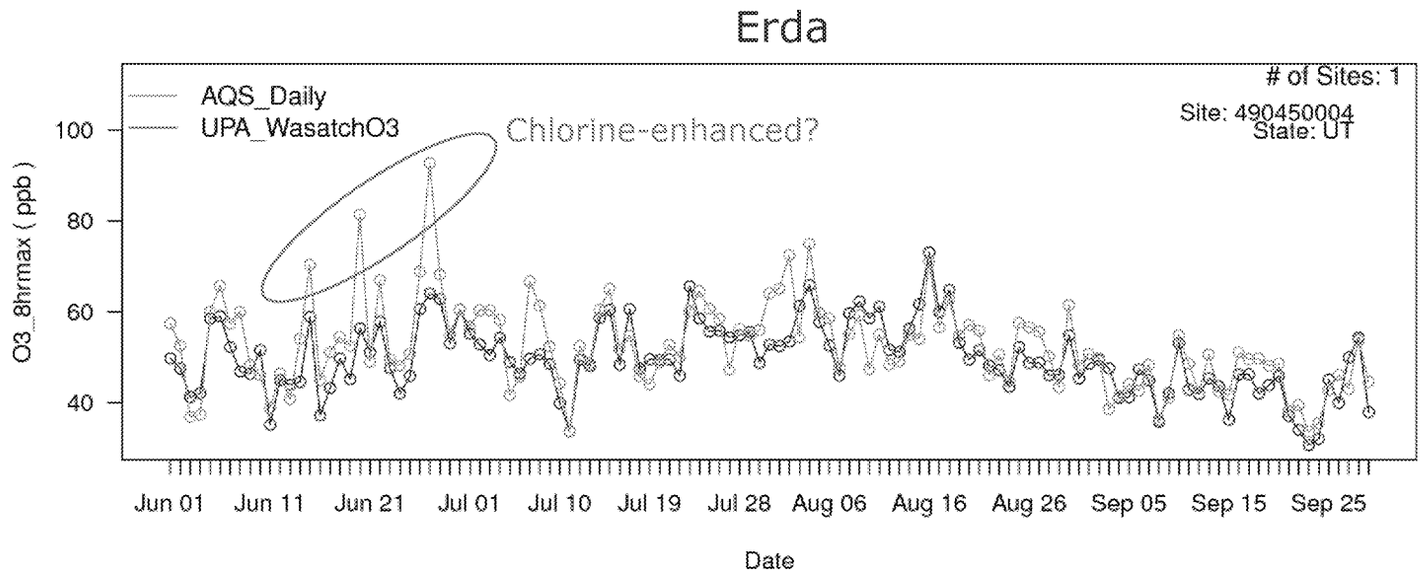


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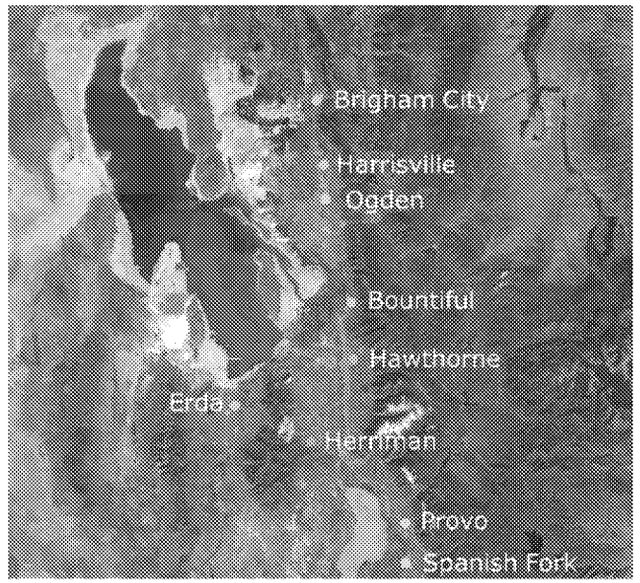


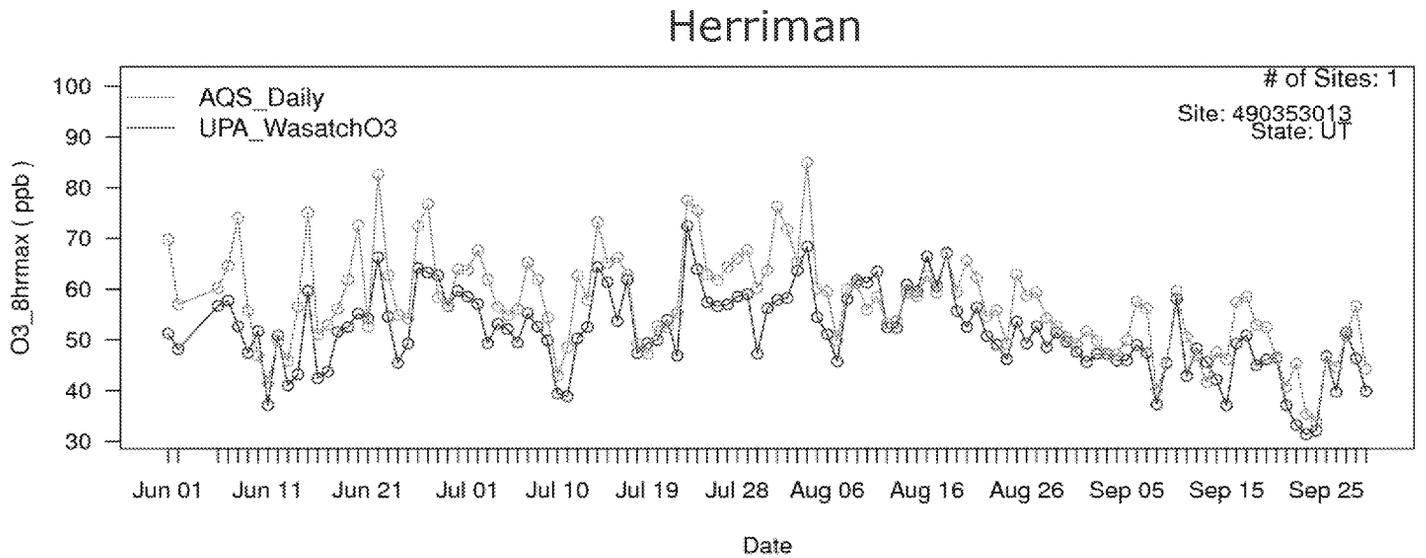


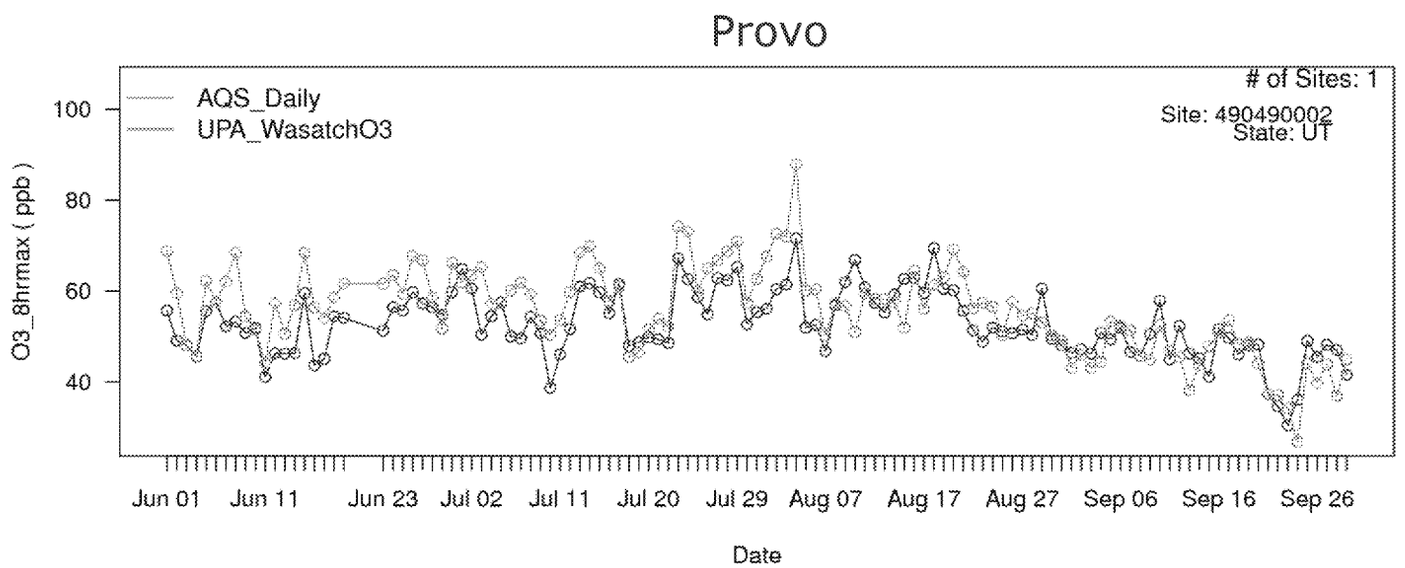


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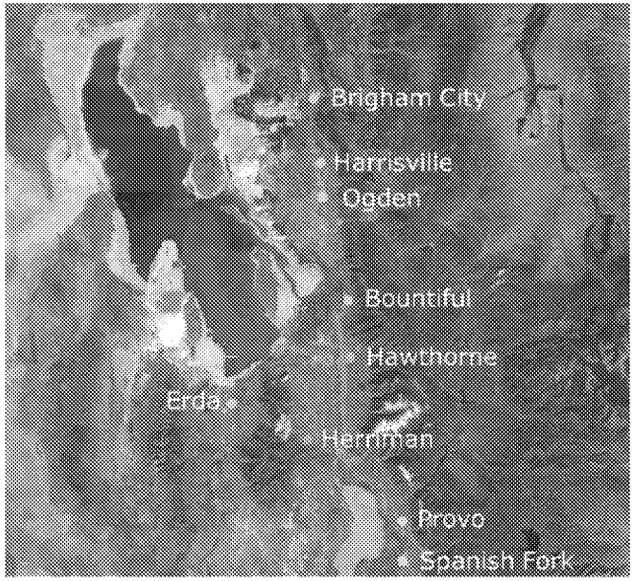


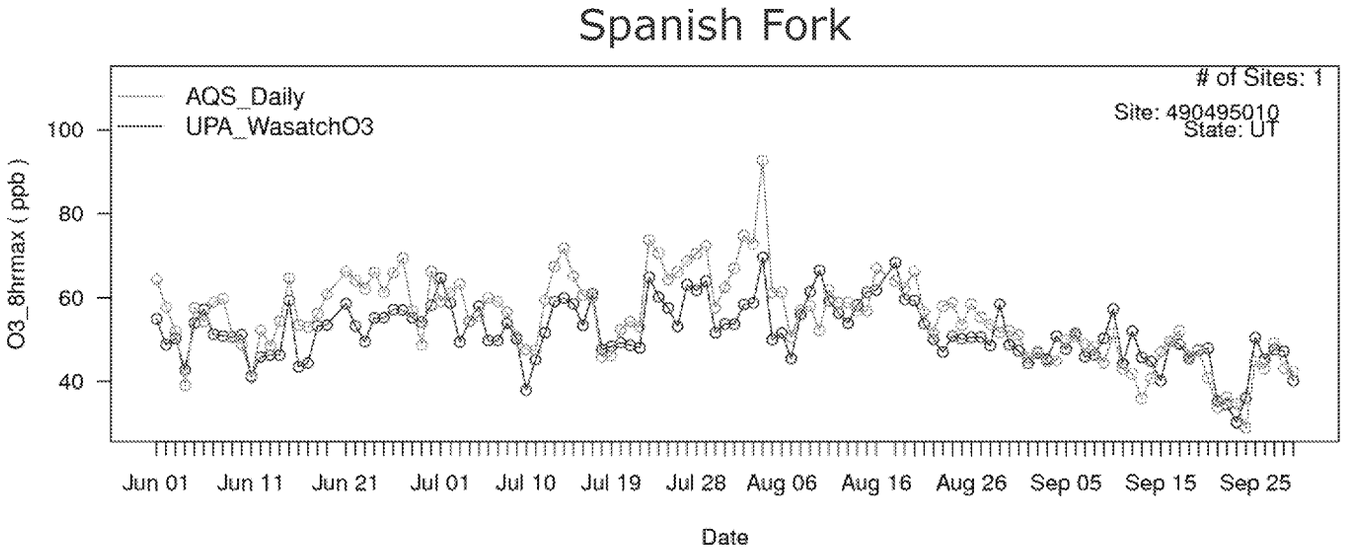


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# CAMx Ozone Source Apportionment (OSAT)

- ZROW is a "brute force" sensitivity: "how does ozone change when I remove source X?"
- OSAT is an alternative: "what is the ozone contribution of source X in the current chemical environment?"
  - The answers to both questions are equivalent for linear problems
  - They differ for non-linear problems like ozone (especially for local sources)
  - Helps to establish an envelope of plausible IAE impacts and provides additional weight of evidence
- Run 2016 V1 CAMx BASE with OSAT (June-September)
  - Analyze tagged IAE (BCs + Canada + Mexico)
    - Also tagged anthropogenic emissions in Utah and rest of US
    - Also tagged natural emissions (Utah, rest of US, international)
  - Process OSAT results same as ZROW, using tagged ozone tracers in RRF calculations

# SMAT DV Scaling Using V1 CAMx OSAT Output

| Site | County | 2013-2017 Average DV[1]* | Modeled RRF | OSAT DV (≤70.9 Attains) |
|---|---|---|---|---|
| Northern Wasatch Front | | | | |
| 490110004 Bountiful | Davis | 74 | 0.8346 | 62.1 |
| 490353006 Hawthorne | Salt Lake | 76 | 0.8293 | 63.2 |
| 490353013 Herriman | Salt Lake | 76 | 0.8224 | 62.5 |
| 490450004 Erda | Tooele | 73 | 0.8375 | 61.1 |
| 490570002 Ogden | Weber | 72 | 0.8297 | 59.7 |
| 490571003 Harrisville | Weber | 72 | 0.8432 | 60.9 |
| Southern Wasatch Front | | | | |
| 490490002 Provo | Utah | 71 | 0.8326 | 59.6 |
| 490495010 Spanish Fork | Utah | 72 | 0.8330 | 59.9 |

[1] SMAT-CE is delivered with DV data up through 2017; these results are directly from SMAT-CE.

* EPA modeling guidance recommends scaling the 3-year average DV: in this case, 2013-2015, 2014-2016, 2015-2017

| Site | County | 2015-2017 DV[1] | Modeled RRF | OSAT DV (≤70.9 Attains) |
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| Northern Wasatch Front | | | | |
| 490110004 Bountiful | Davis | 75 | 0.8346 | 62.5 |
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| 490570002 Ogden | Weber | 73 | 0.8297 | 60.5 |
| 490571003 Harrisville | Weber | 73 | 0.8432 | 61.5 |
| Southern Wasatch Front | | | | |
| 490490002 Provo | Utah | 72 | 0.8326 | 59.9 |
| 490495010 Spanish Fork | Utah | 71 | 0.8330 | 59.1 |

[1] Using latest DV available in SMAT-CE; these results are directly from SMAT-CE.

| Site | County | 2016-2018 DV[1] | Modeled RRF | OSAT DV (≤70.9 Attains) |
|---|---|---|---|---|
| Northern Wasatch Front | | | | |
| 490110004 Bountiful | Davis | 78 | 0.8346 | 65.1 |
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| 490353013 Herriman | Salt Lake | 77 | 0.8224 | 63.3 |
| 490450004 Erda | Tooele | 74 | 0.8375 | 62.0 |
| 490570002 Ogden | Weber | 75 | 0.8297 | 62.2 |
| 490571003 Harrisville | Weber | 74 | 0.8432 | 62.4 |
| Southern Wasatch Front | | | | |
| 490490002 Provo | Utah | N/A | 0.8326 | N/A |
| 490495010 Spanish Fork | Utah | 72 | 0.8330 | 60.0 |

[1] Using latest EPA-official DV; these results apply RRF to 2016-2018 DV outside of SMAT-CE.

| Site | County | 2017-2019 DV[1] | Modeled RRF | OSAT DV (≤70.9 Attains) |
|---|---|---|---|---|
| Northern Wasatch Front | | | | |
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| 490570002 Ogden | Weber | 71 | 0.8297 | 58.9 |
| 490571003 Harrisville | Weber | 71 | 0.8432 | 59.9 |
| Southern Wasatch Front | | | | |
| 490490002 Provo | Utah | N/A | 0.8326 | N/A |
| 490495010 Spanish Fork | Utah | 70 | 0.8330 | 58.3 |

[1] Using latest EPA-official DV; these results apply RRF to 2017-2019 DV outside of SMAT-CE.

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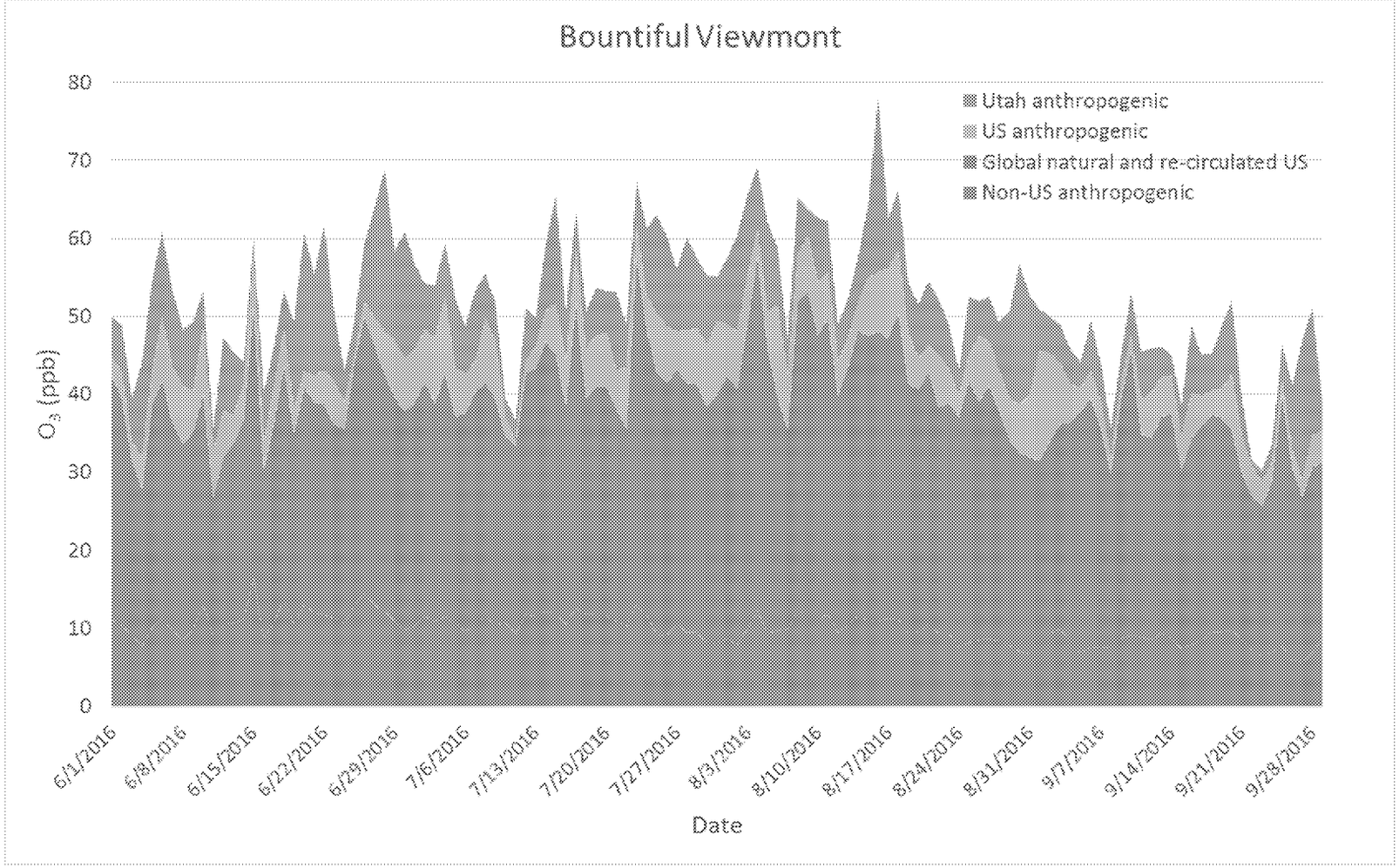
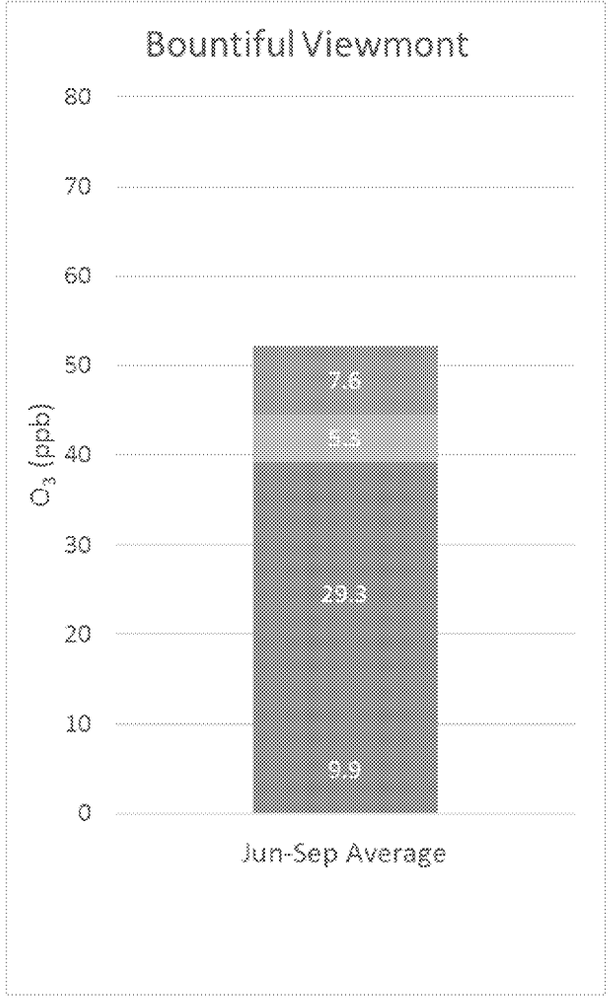
In every case ZROW results in DV<<70 ppb, well within attainment

# MDA8 Ozone Source Apportionment Results
# Daily Apportionment by Region/Sector

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# Takeaway Summary

- Beta CMAQ & V1 CAMx performance is generally good & within benchmarks
  - At levels typically achieved for SIP modeling
  - Well-simulated US Background + US Regional ozone at Gothic site in Colorado
  - Evidence points to lack of local ozone production
  - ➢ International contribution in DV scaling may be over estimated, but by <2 ppb
- Beta CMAQ ZROW and V1 CAMx OSAT result in projected DV<70.9 ppb at all sites
  - CMAQ & CAMx absolute contributions bracket needed 7.1 ppb DV reduction at the limiting site: 6.7-9.9 ppb

# End

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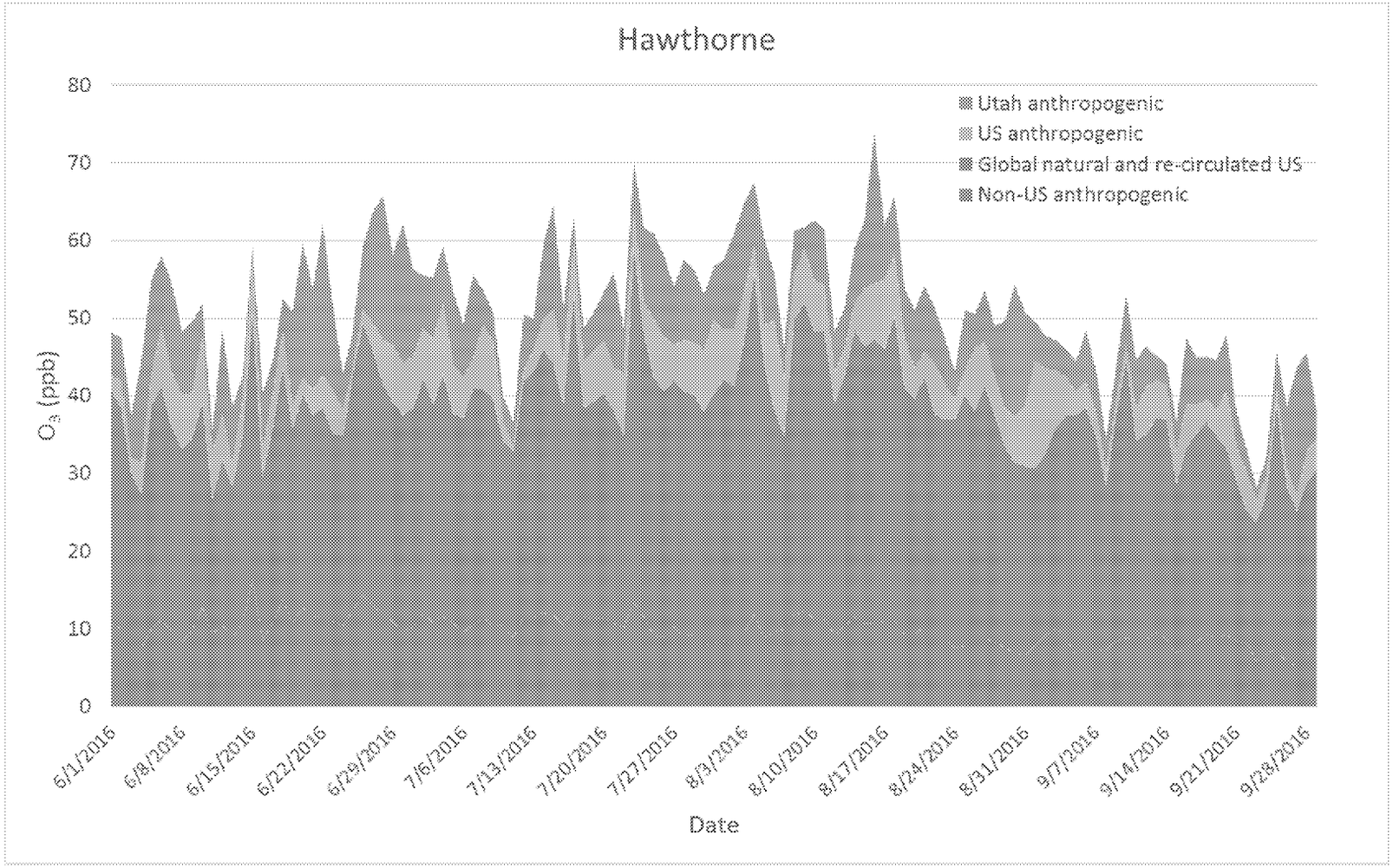
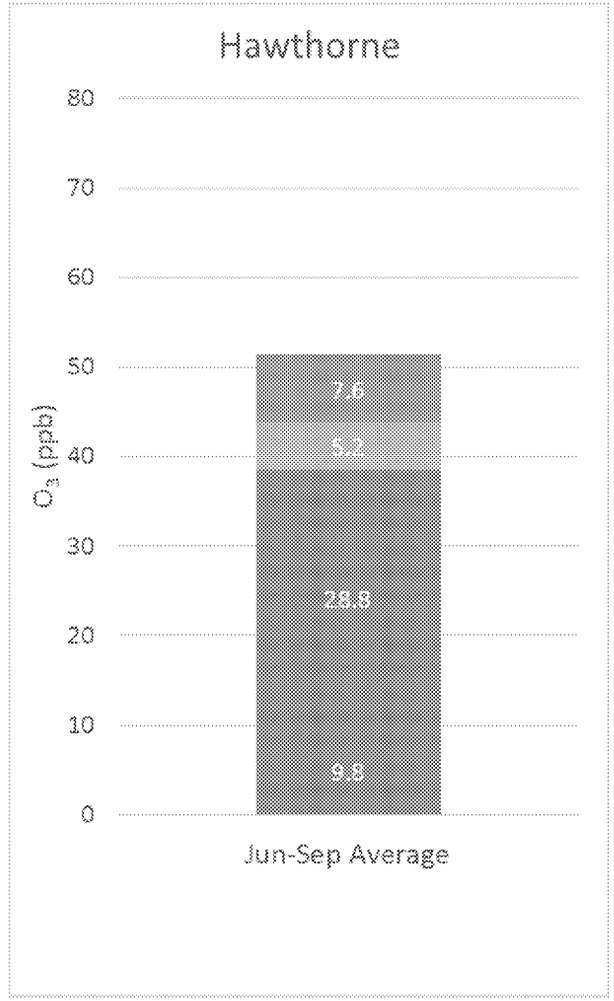
# MDA8 Ozone Source Apportionment Results
# Daily Apportionment by Region/Sector

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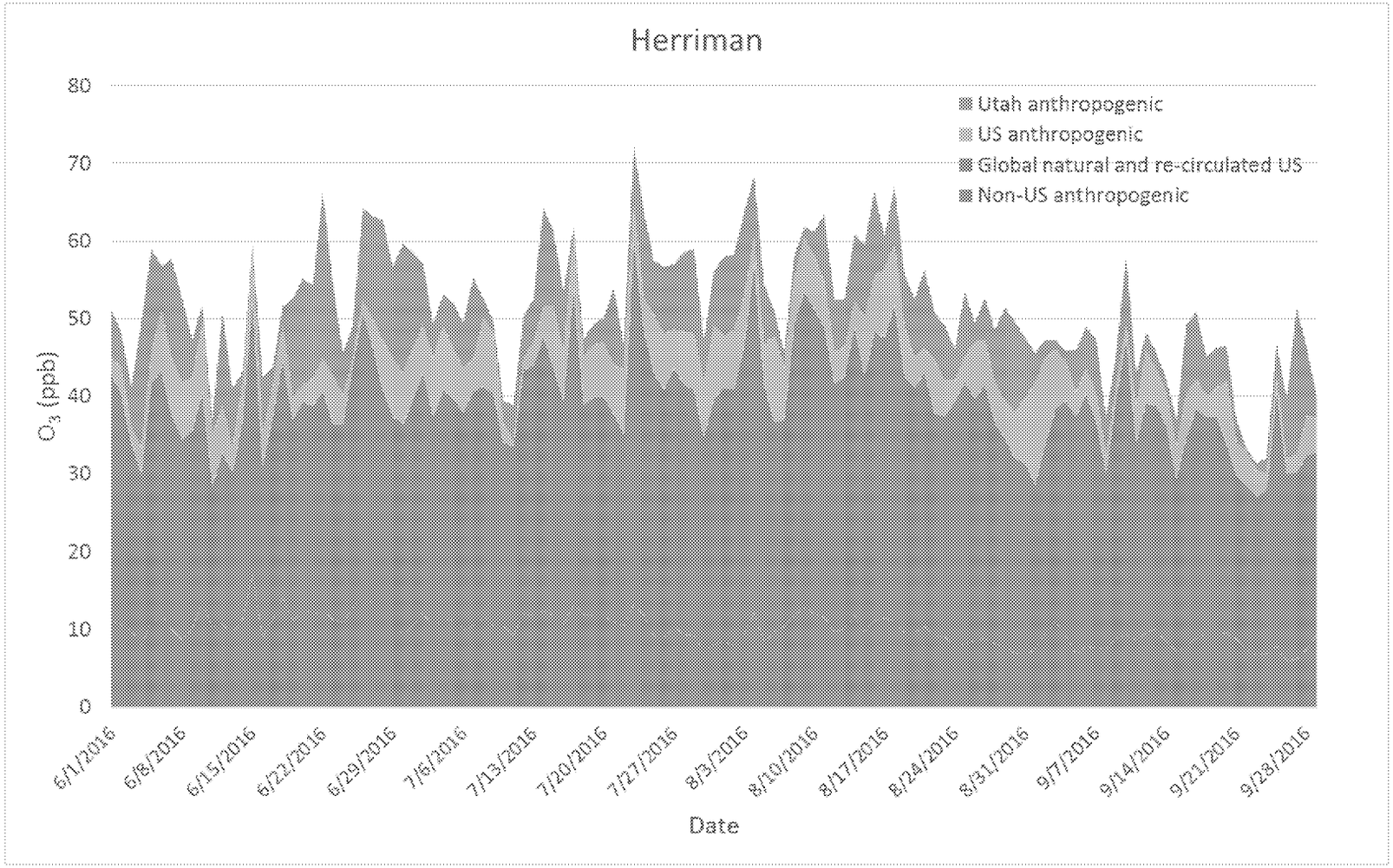
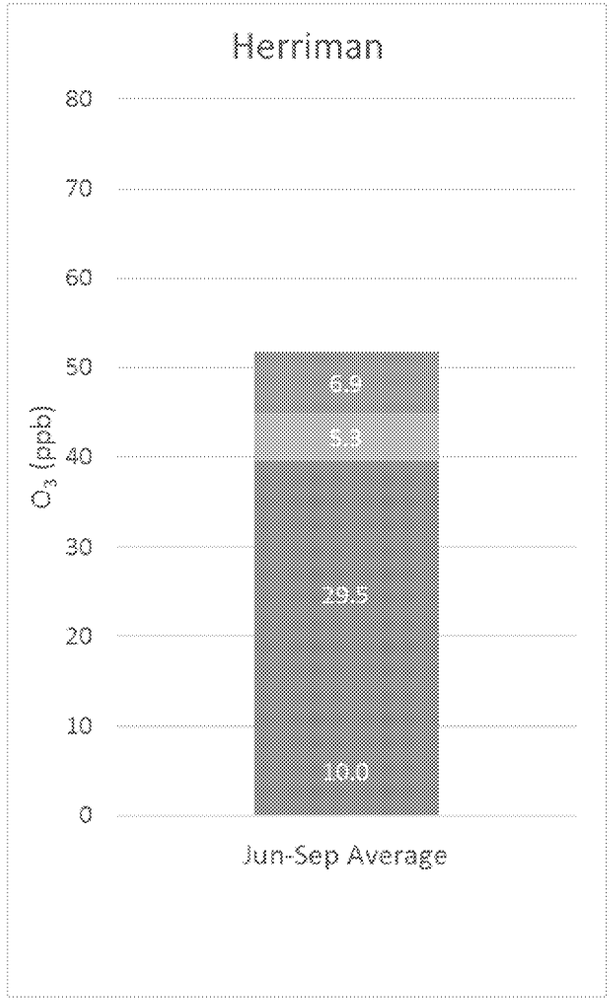
# Daily Apportionment by Region/Sector

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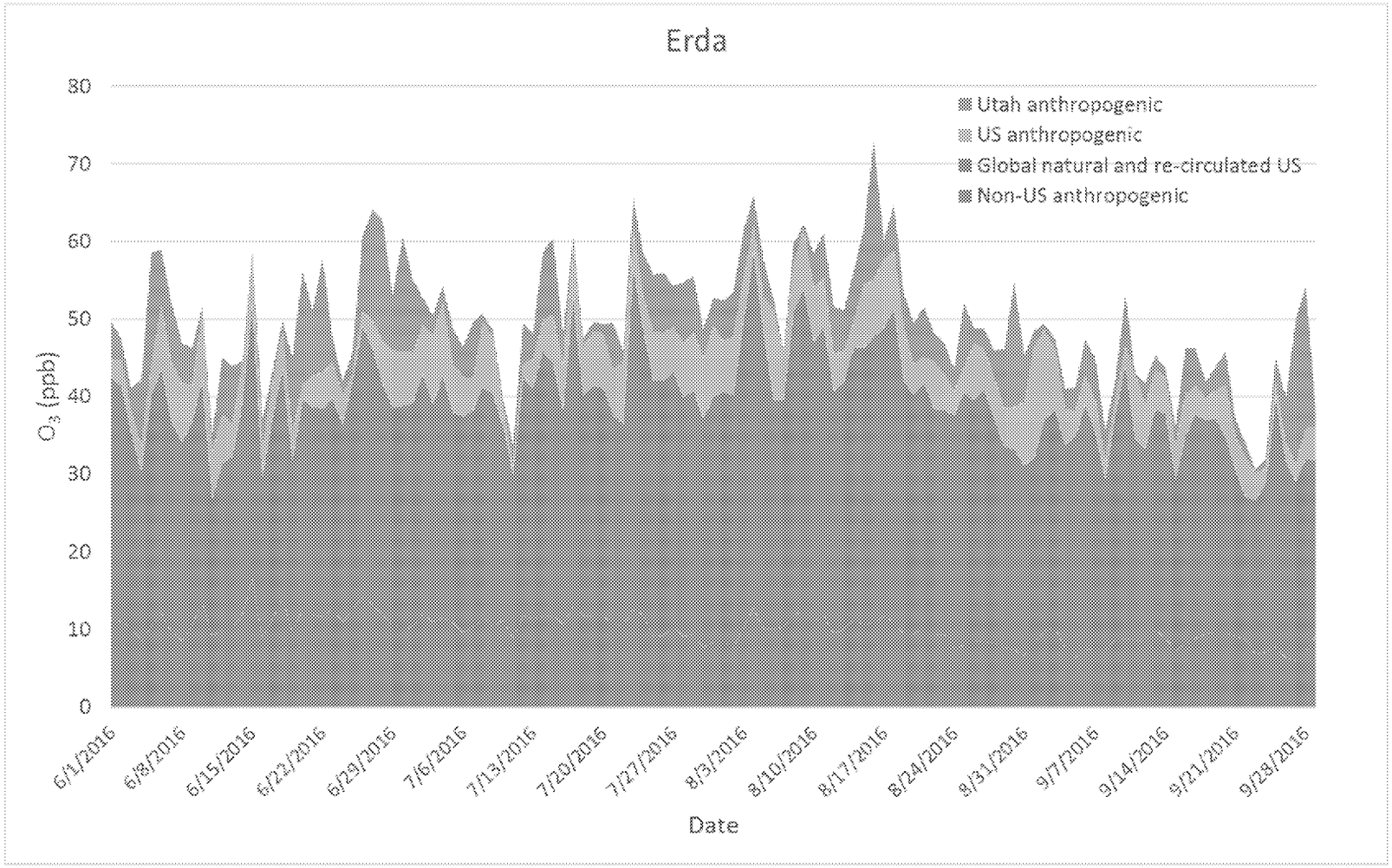


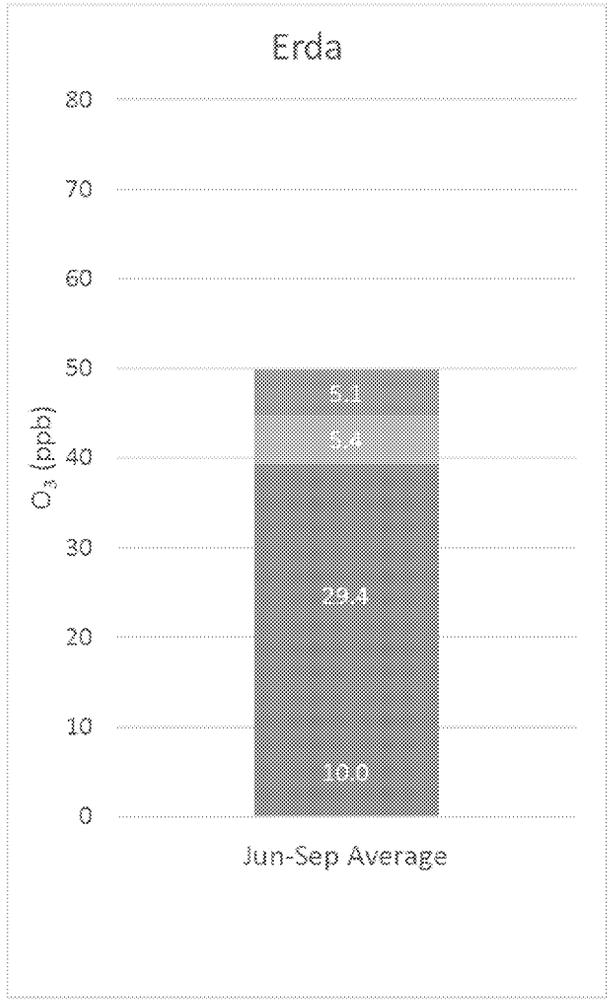


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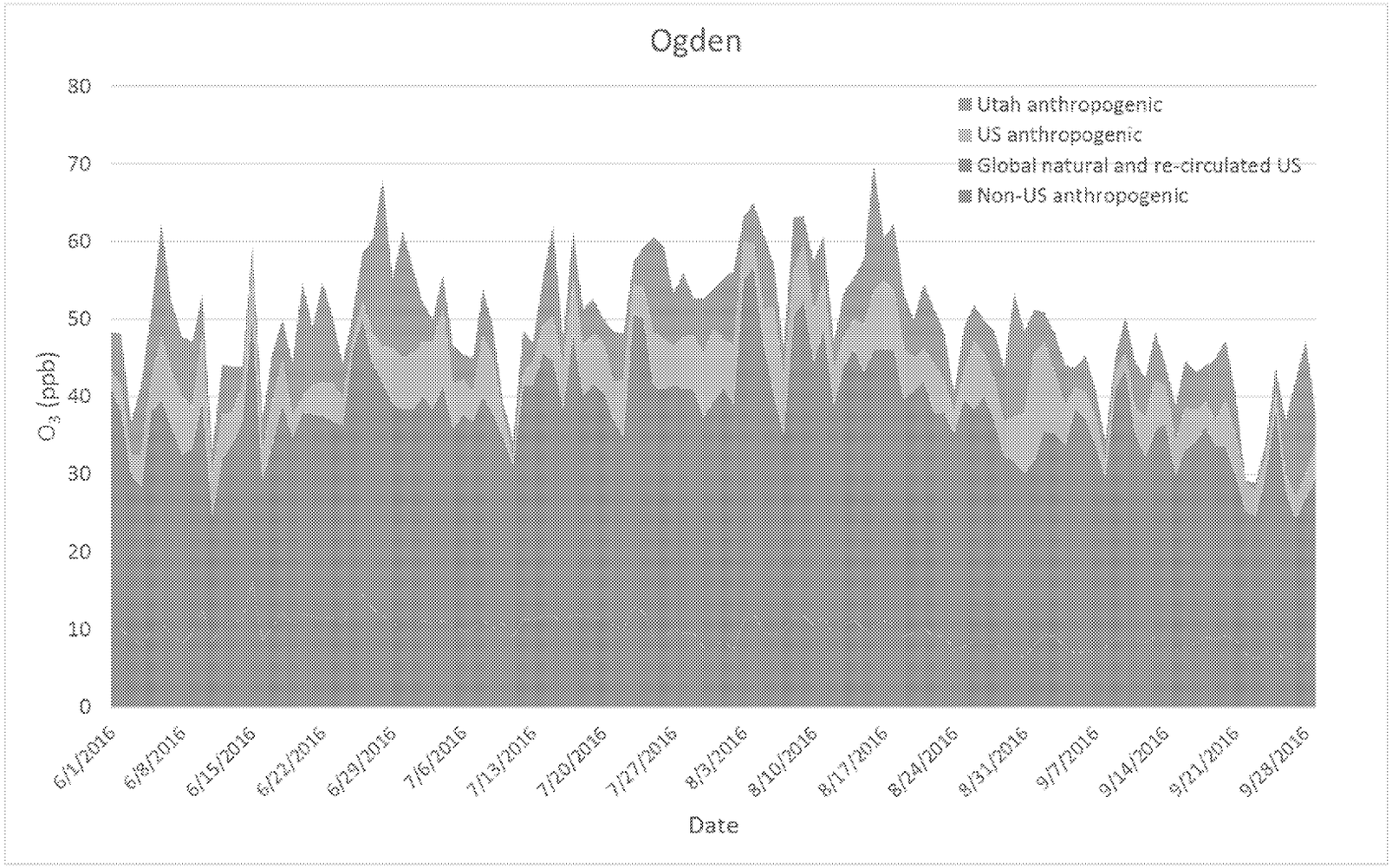


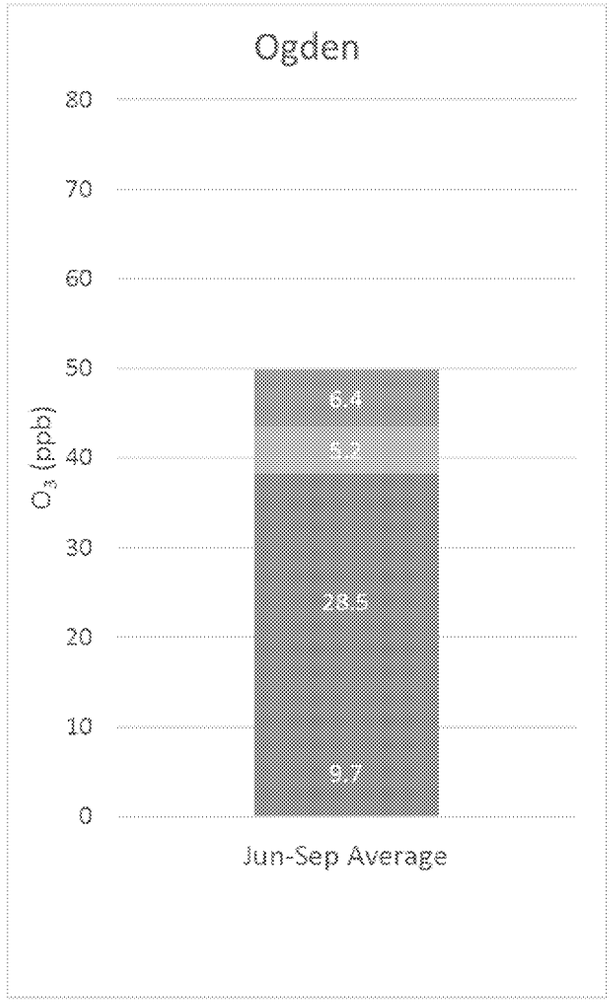


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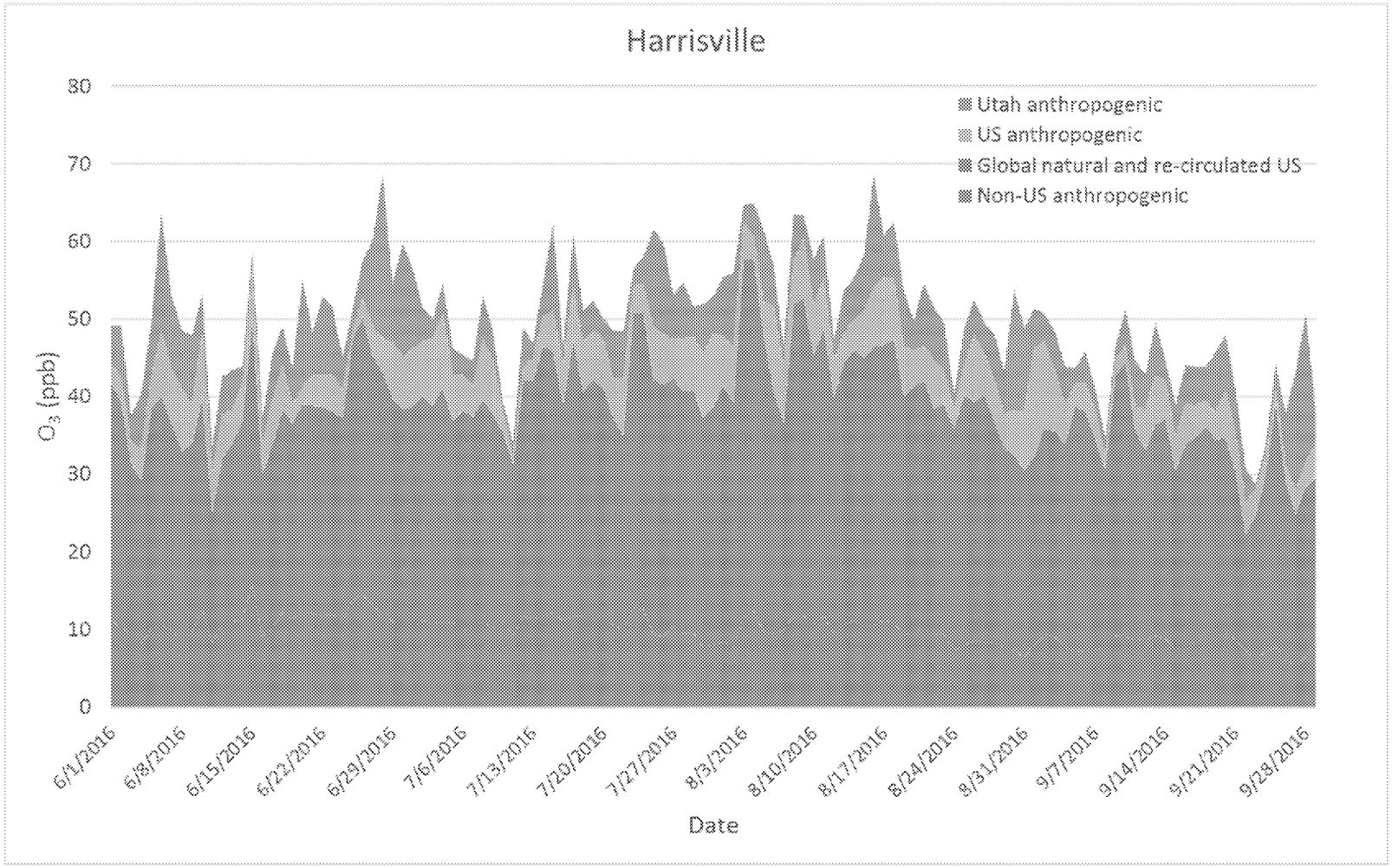


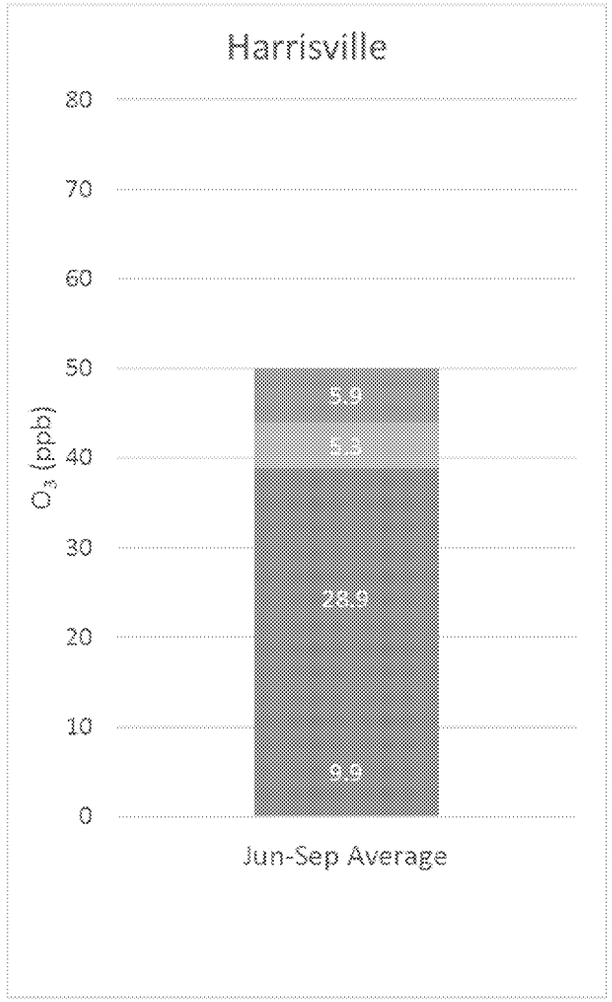


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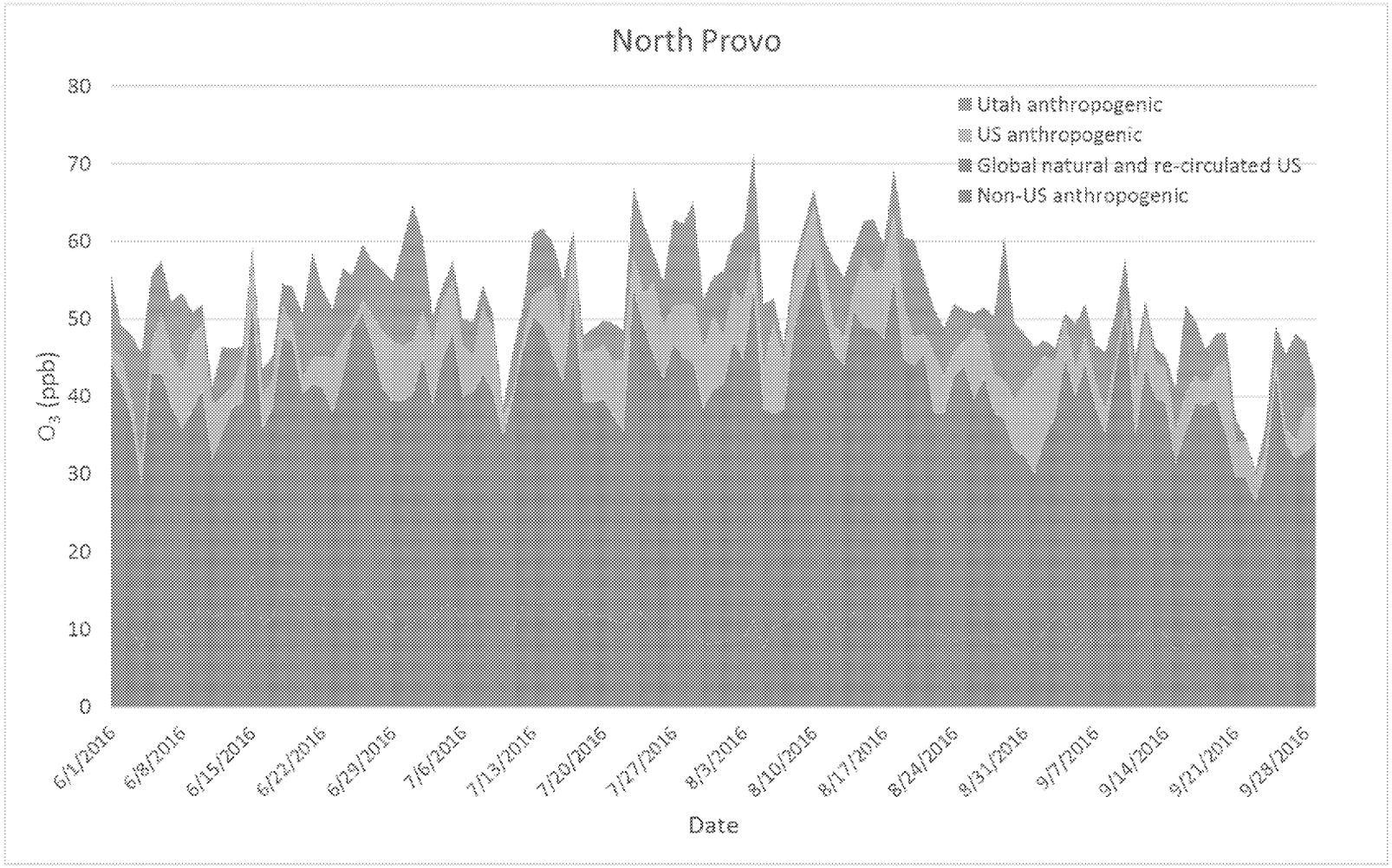


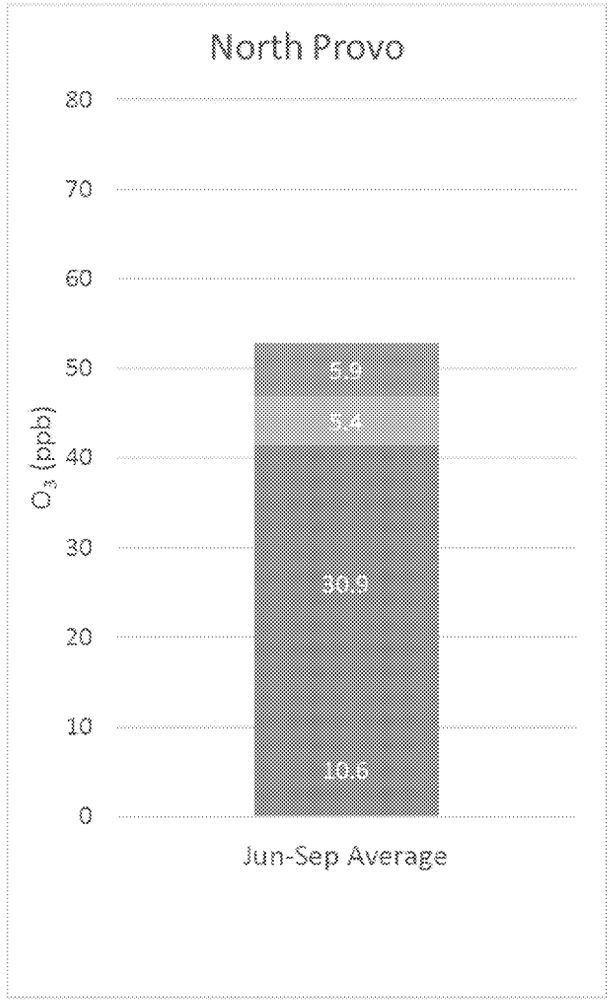


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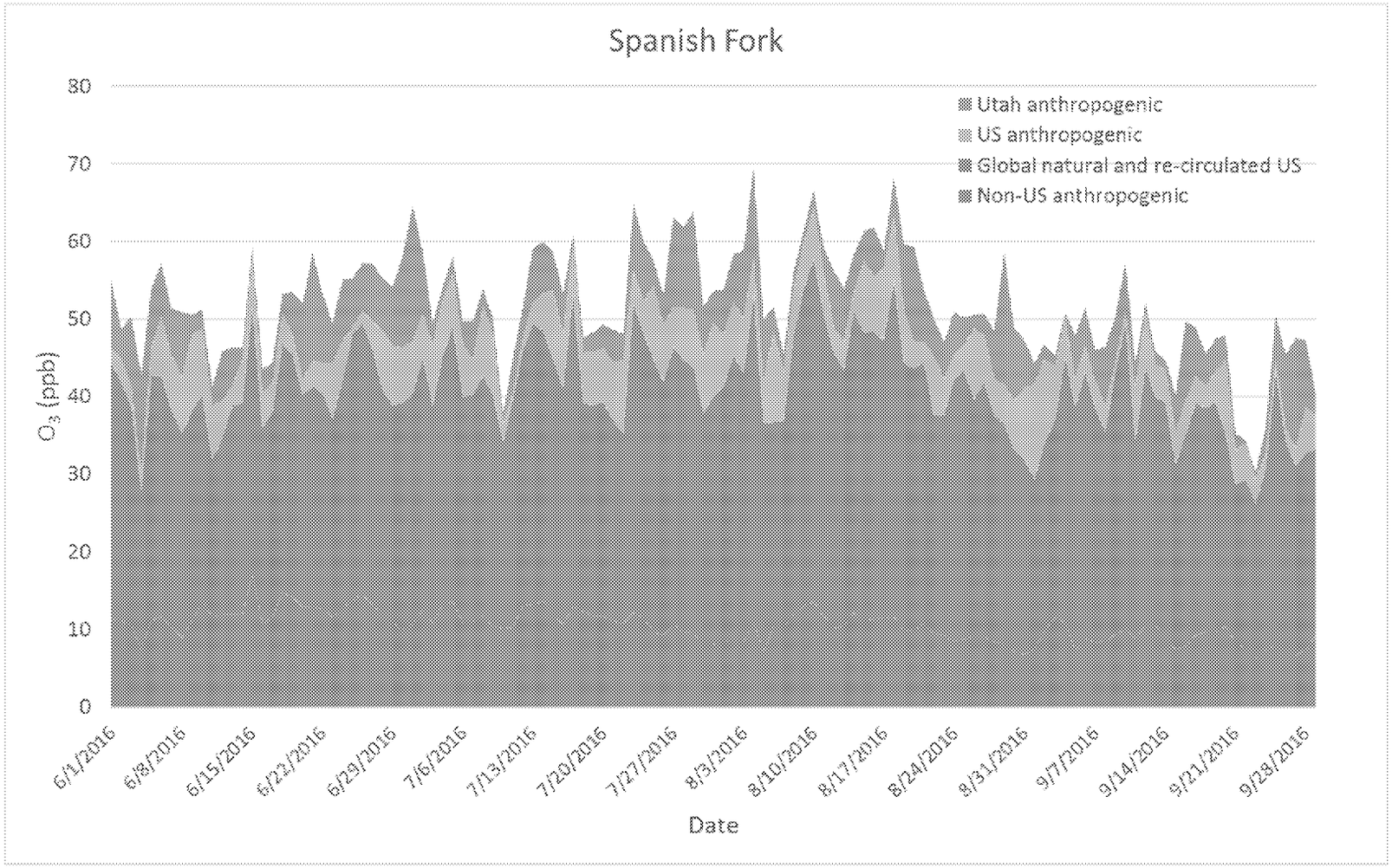
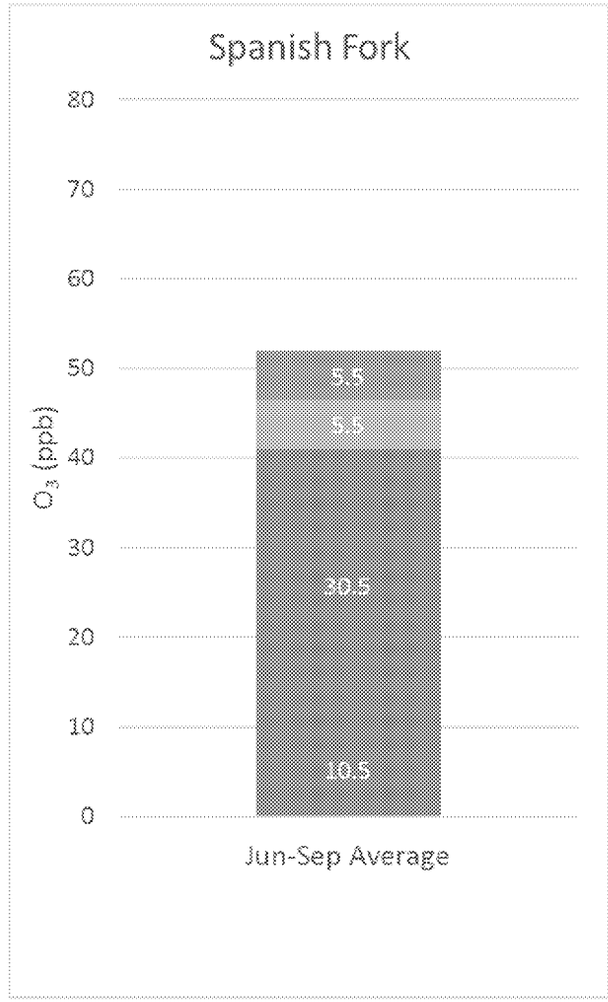
# Daily Apportionment by Region/Sector

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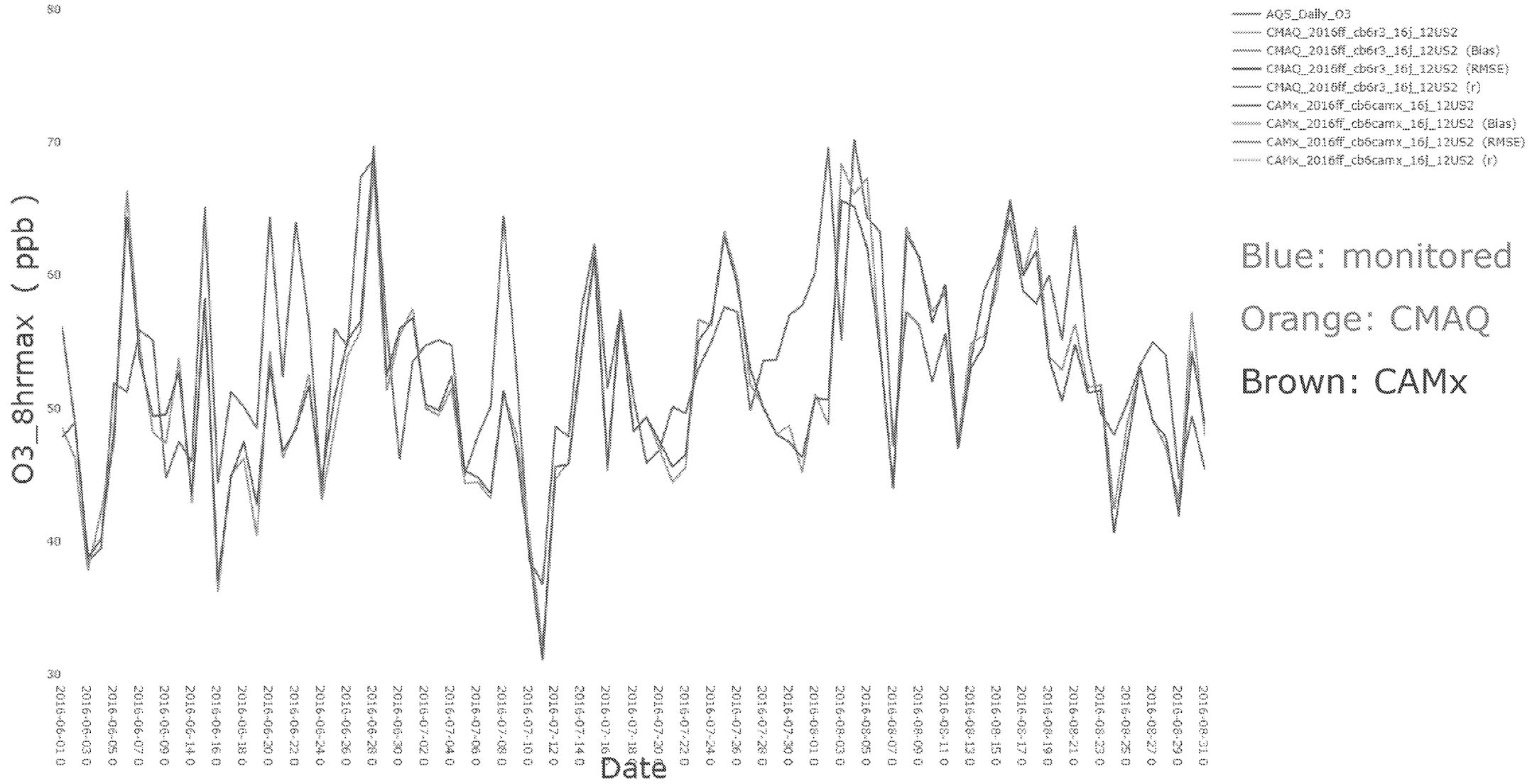
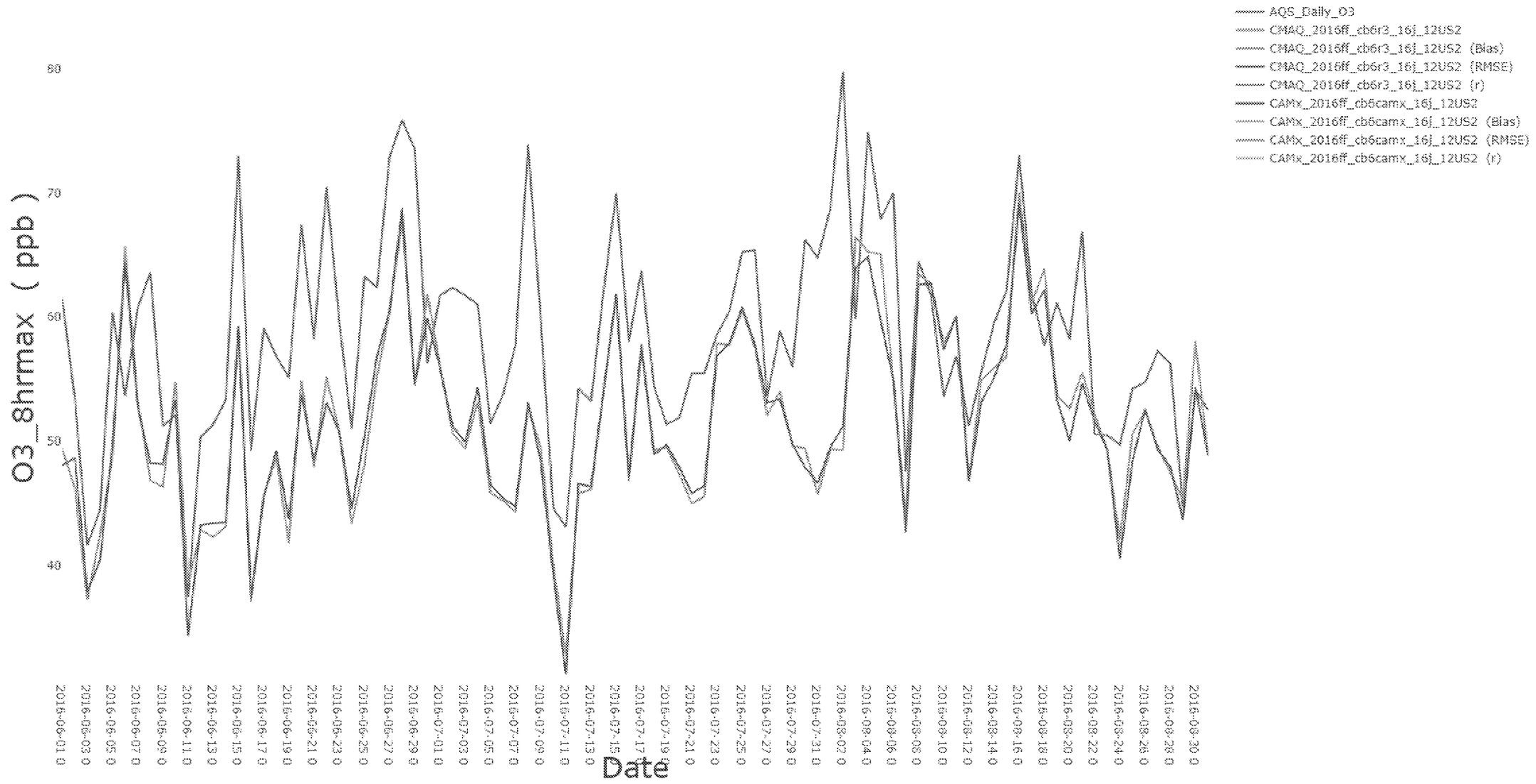
# Beta MDA8 Ozone Time Series – Brigham City

CMAQ_2016ff_cb6r3_16j_12US2 O3_8hrmax for AQS_Daily_O3 Site: 490030003 in UT



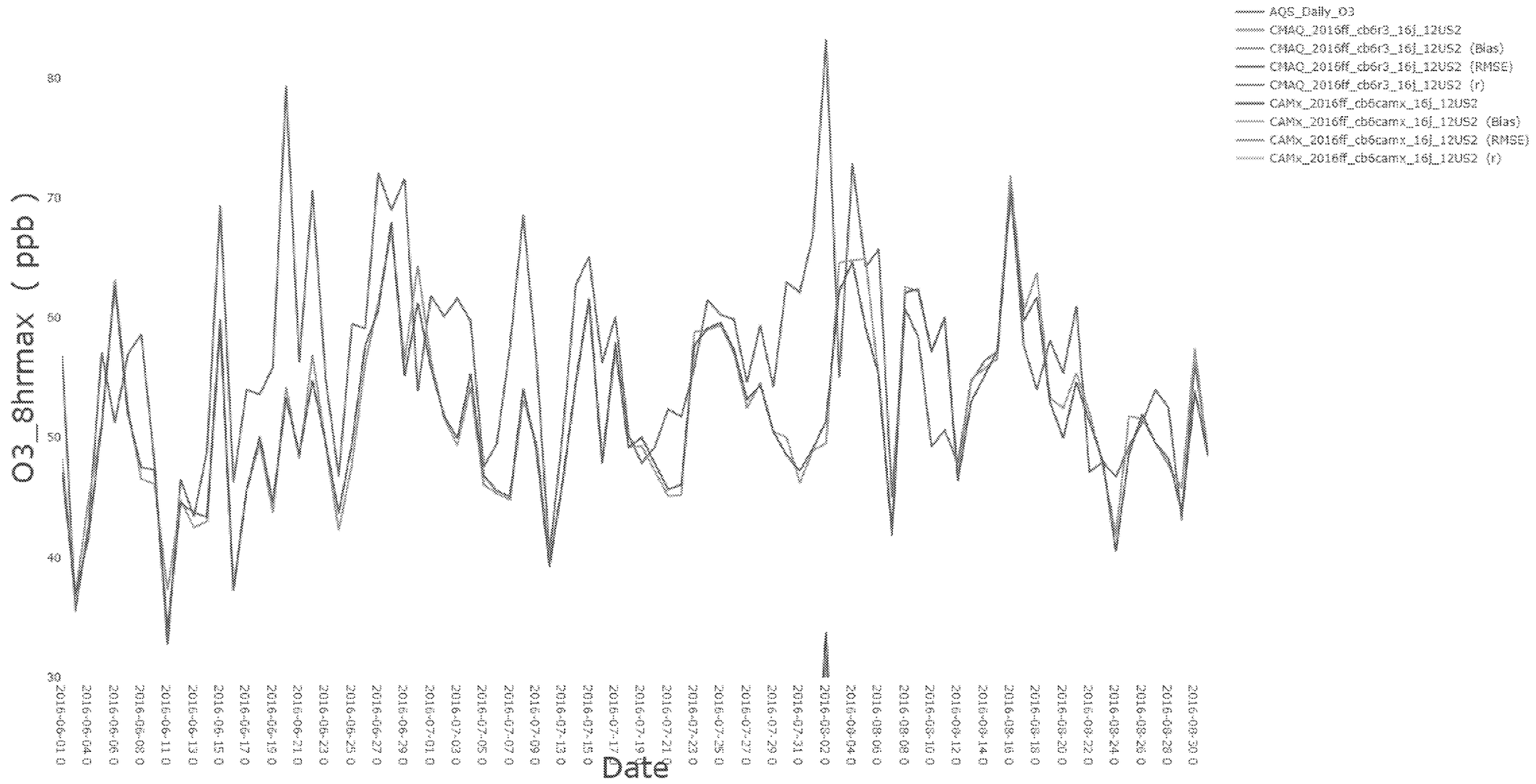
# Beta MDA8 Ozone Time Series – Harrisville

CMAQ_2016ff_cb6r3_16j_12US2 O3_8hrmax for AQS_Daily_O3 Site: 490571003 in UT



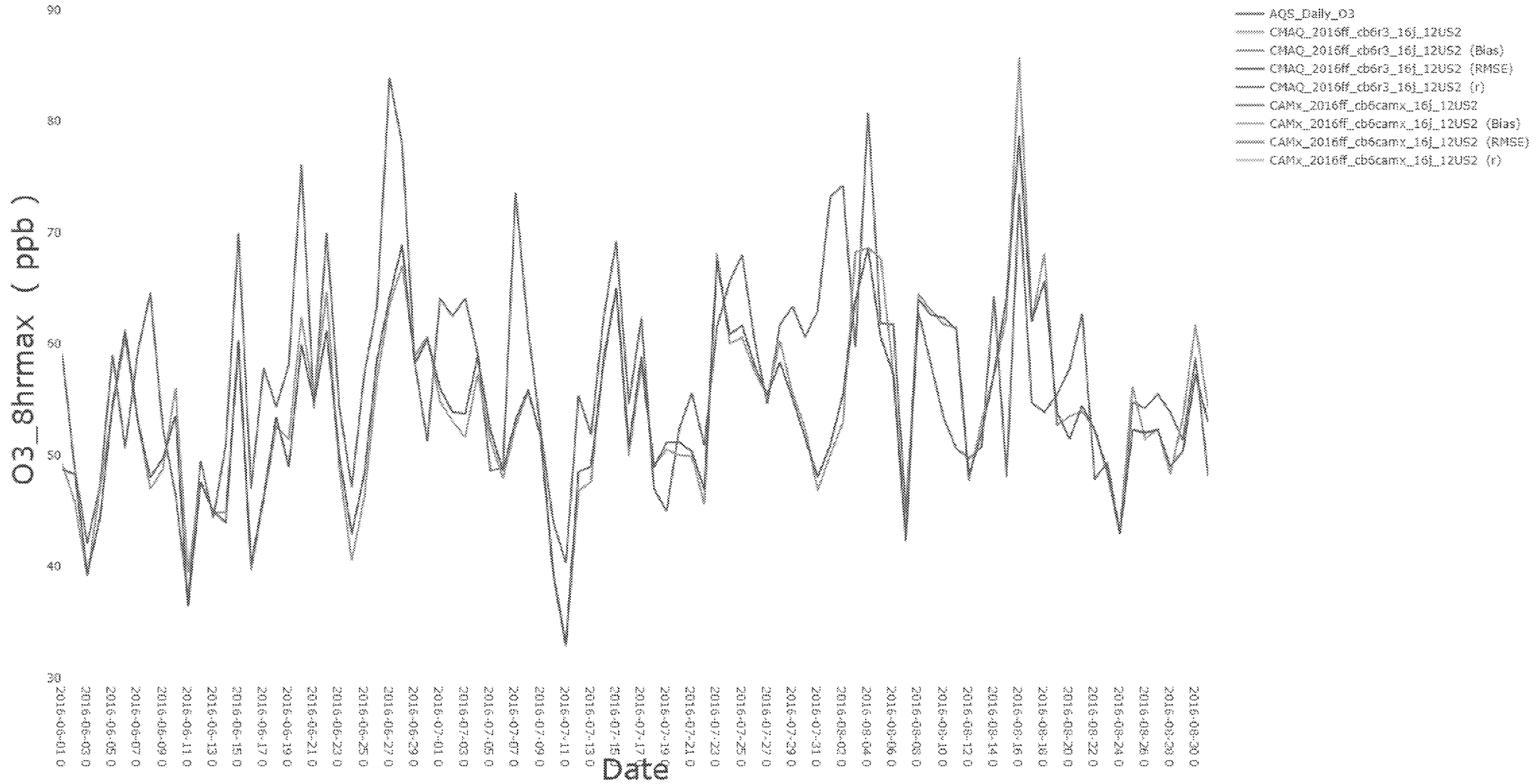
# Beta MDA8 Ozone Time Series – Ogden

CMAQ_2016ff_cb6r3_16j_12US2 O3_8hrmax for AQS_Daily_O3 Site: 490570002 in UT



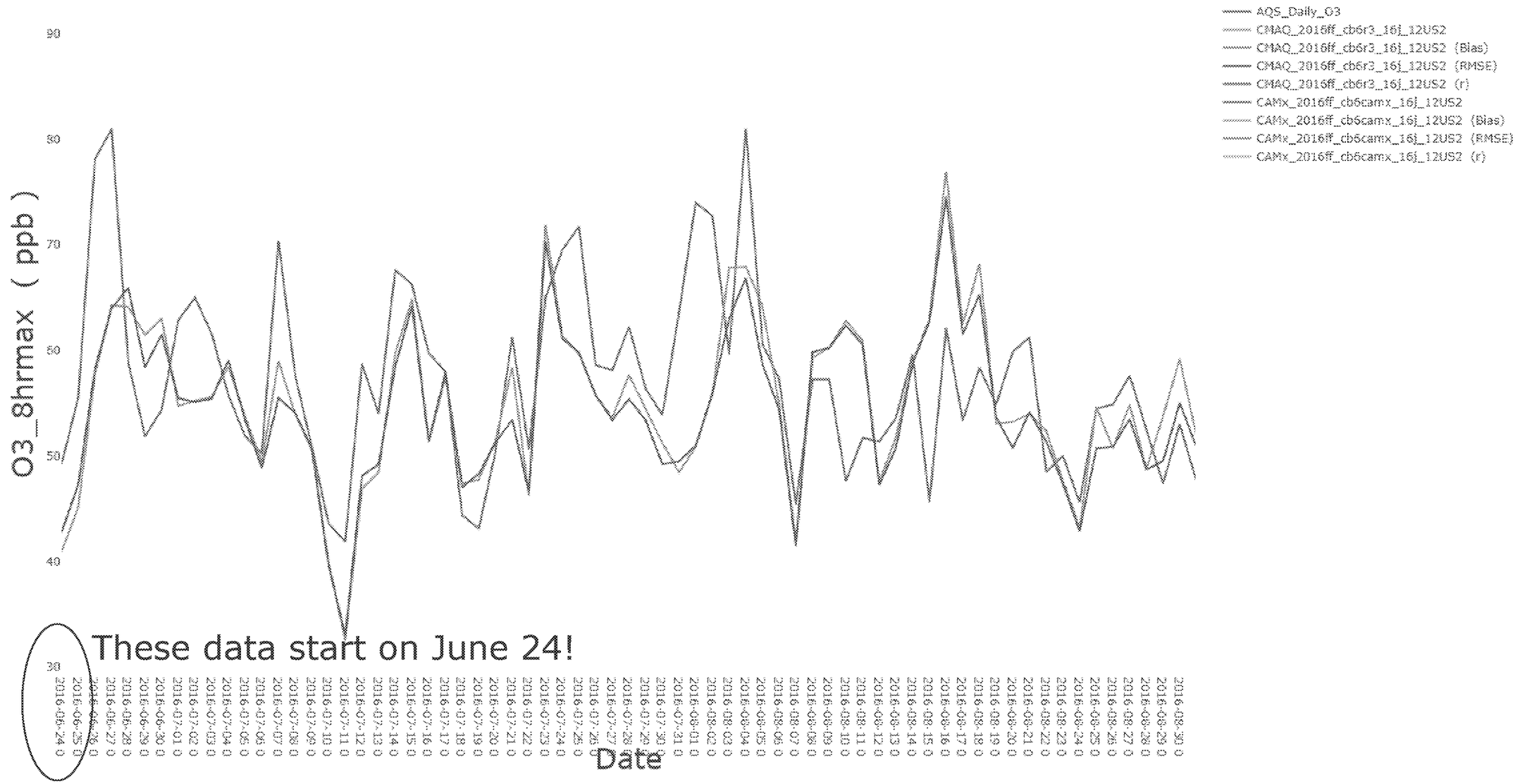
# Beta MDA8 Ozone Time Series – Bountiful

CMAQ_2016ff_cb6r3_16j_12US2 O3_8hrmax for AQS_Daily_O3 Site: 490110004 in UT



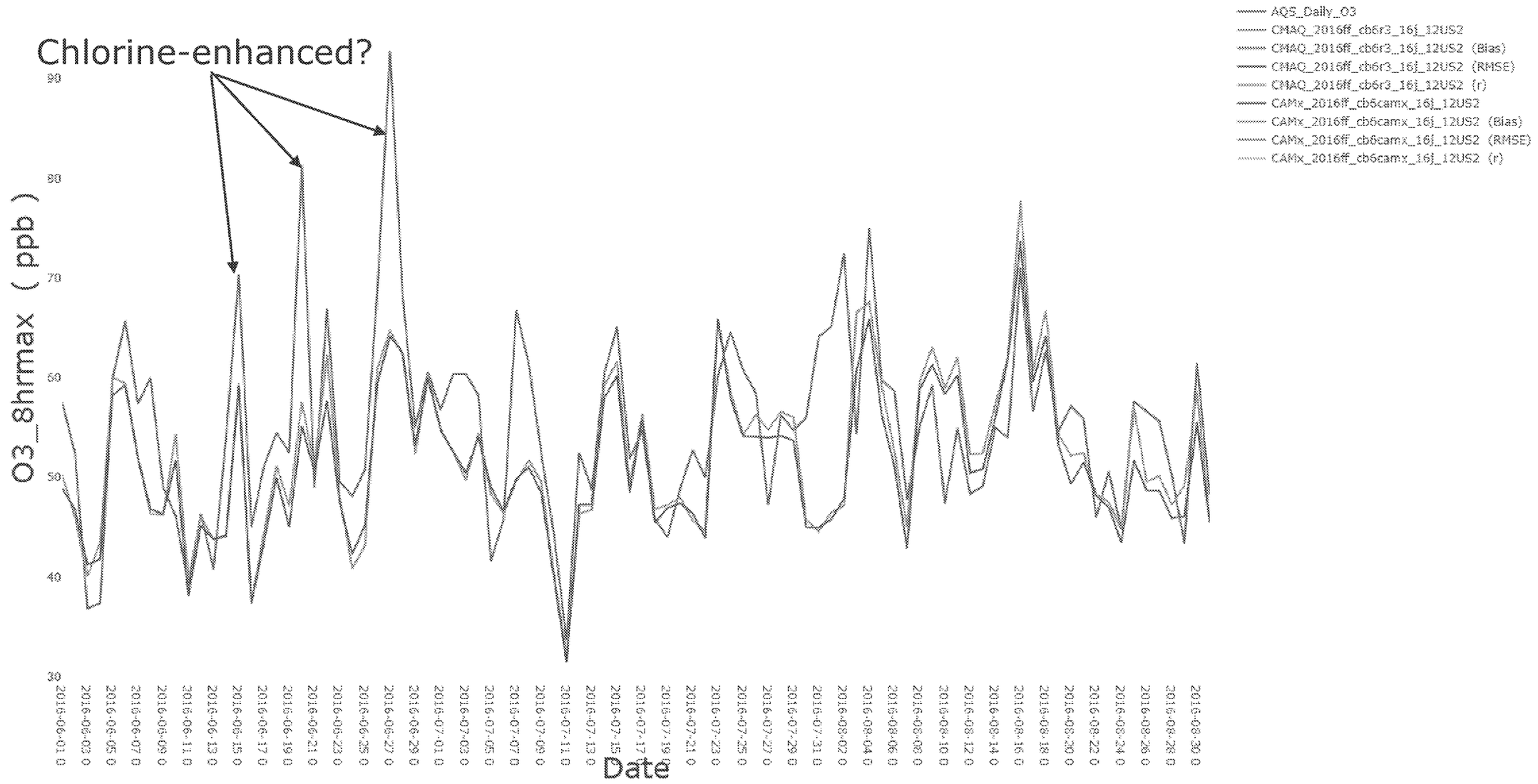
# Beta MDA8 Ozone Time Series – Hawthorne

CMAQ_2016ff_cb6r3_16j_12US2 O3_8hrmax for AQS_Daily_O3 Site: 490353006 in UT



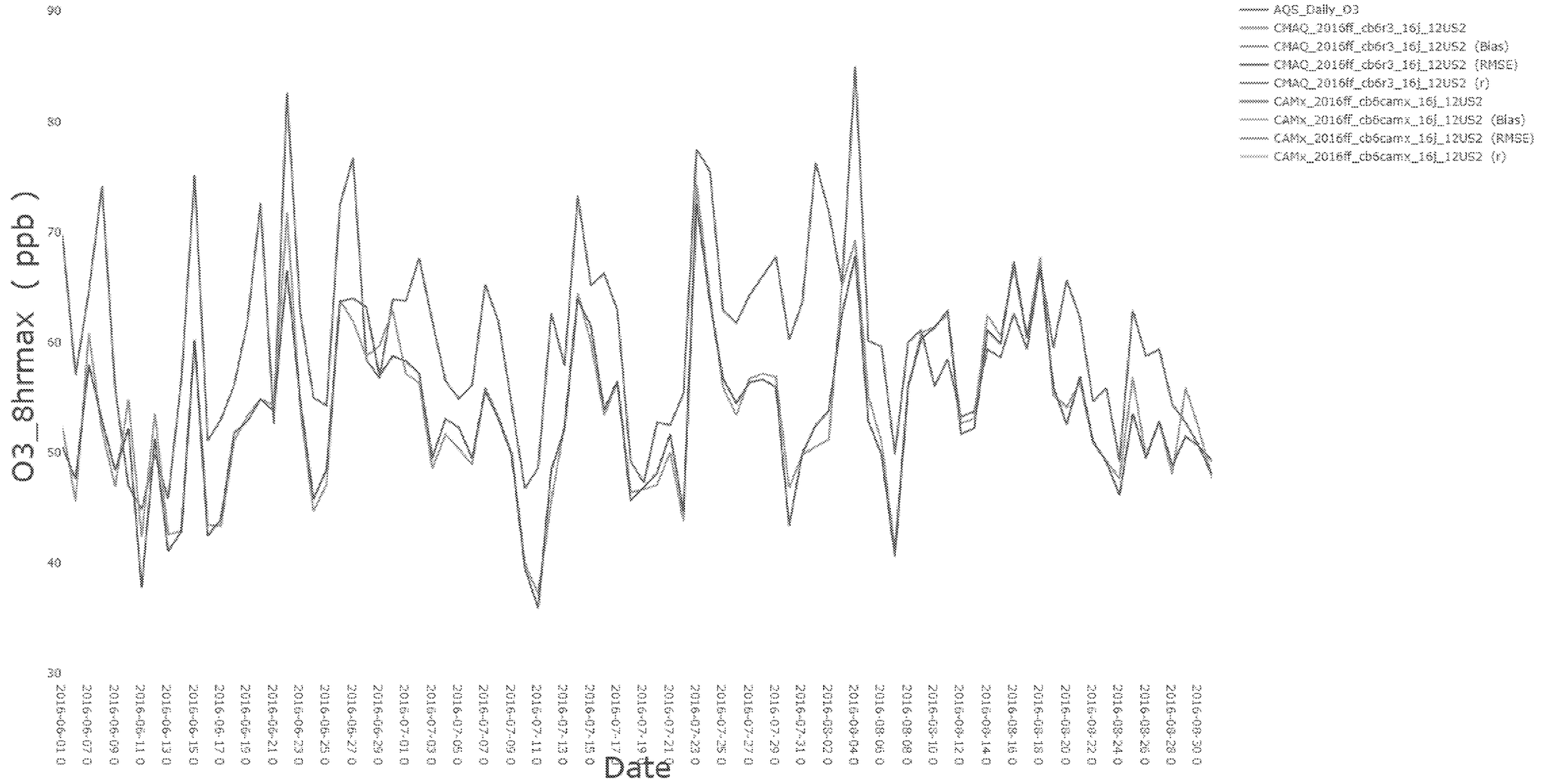
# Beta MDA8 Ozone Time Series – Erda

CMAQ_2016ff_cb6r3_16j_12US2 O3_8hrmax for AQS_Daily_O3 Site: 490450004 in UT

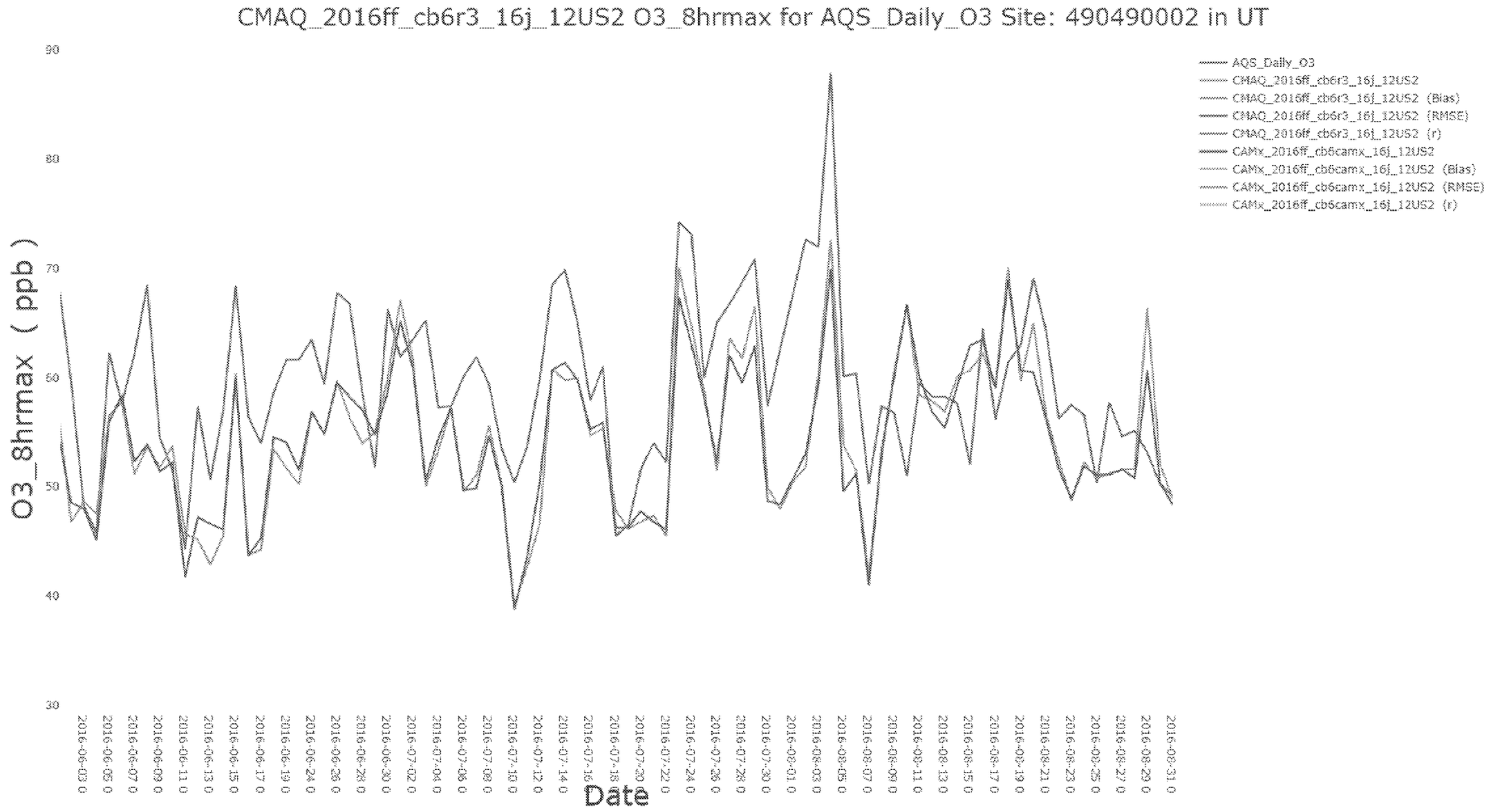


# Beta MDA8 Ozone Time Series – Herriman

CMAQ_2016ff_cb6r3_16j_12US2 O3_8hrmax for AQS_Daily_O3 Site: 490353013 in UT

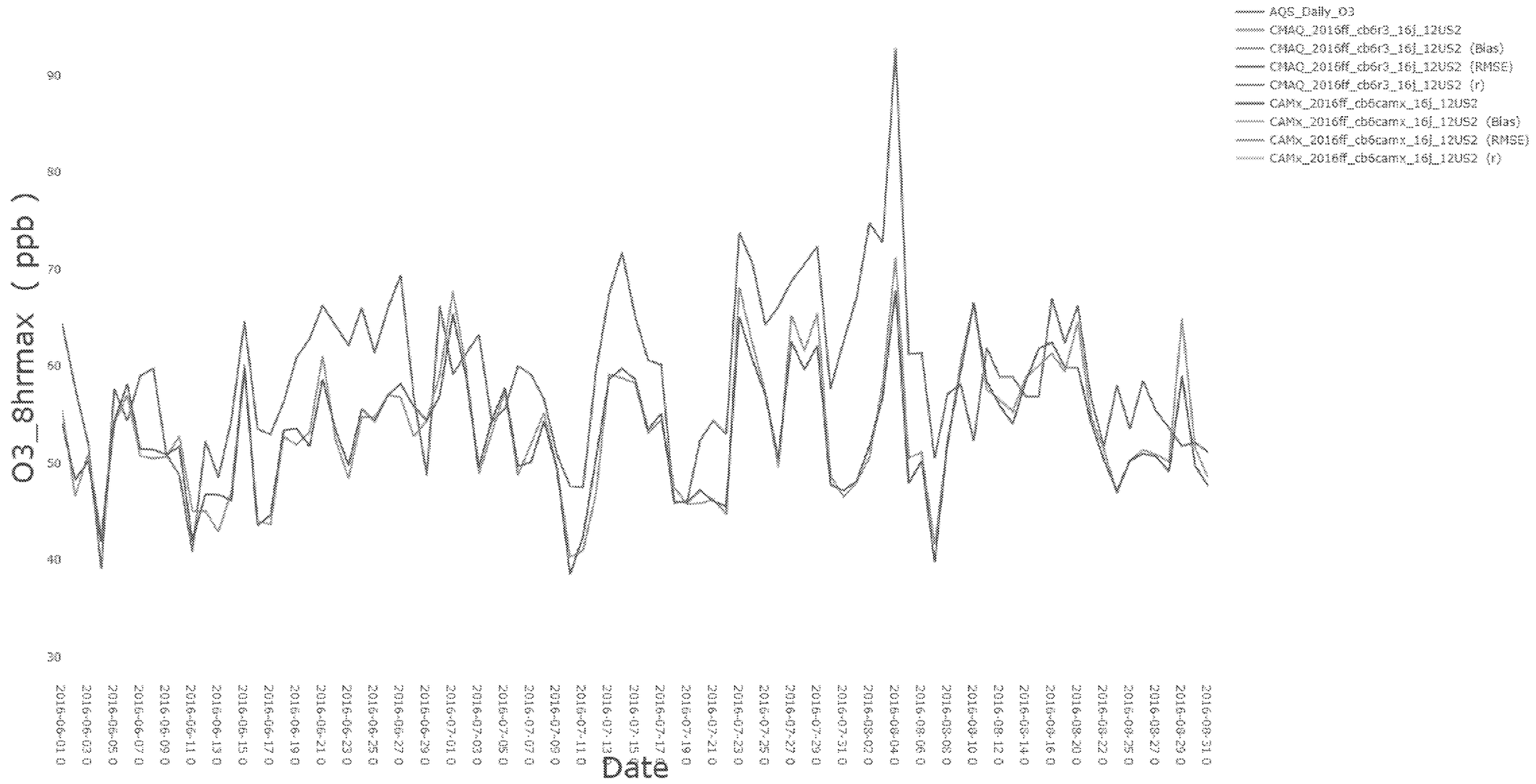


# Beta MDA8 Ozone Time Series – Provo



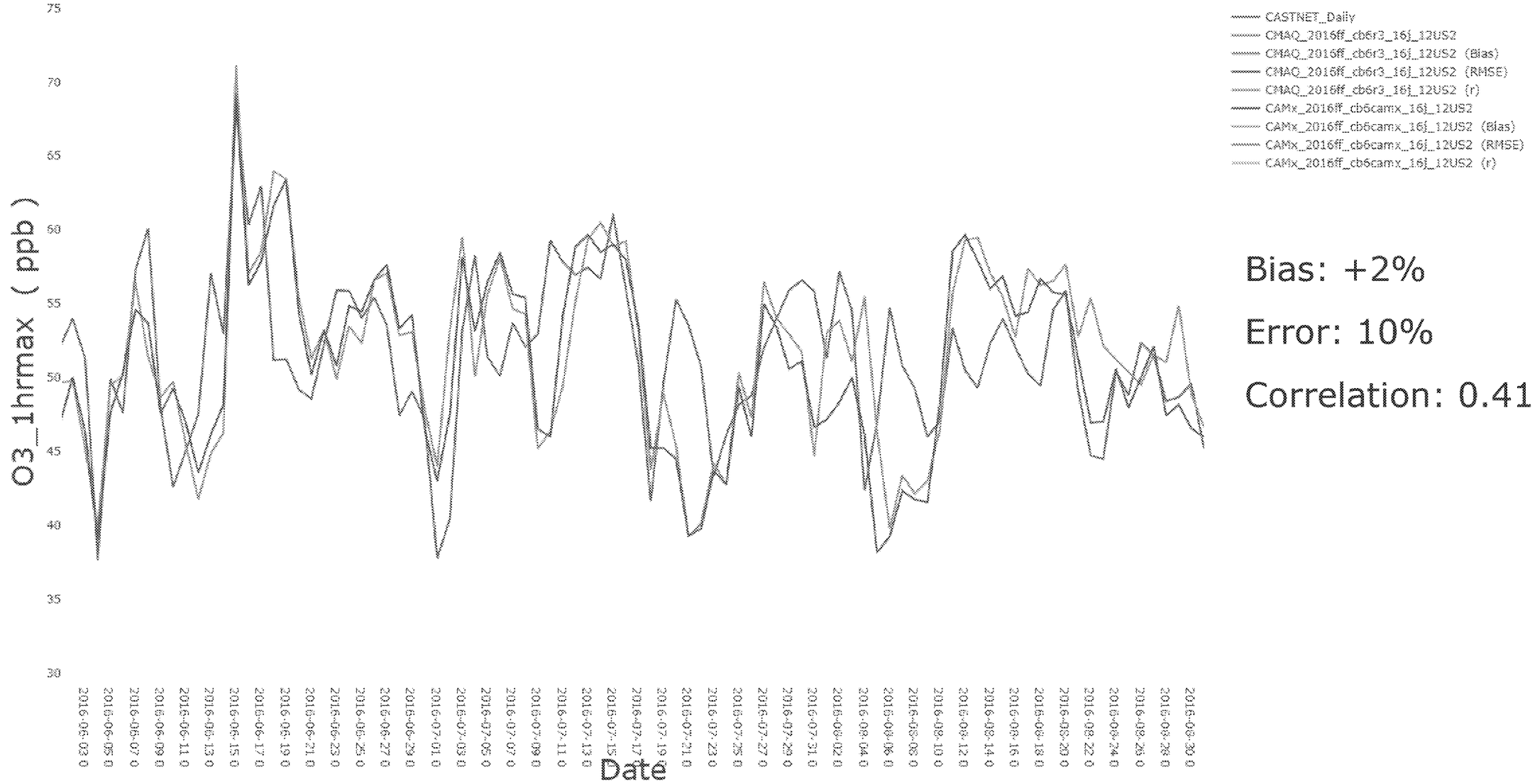
# Beta MDA8 Ozone Time Series – Spanish Fork

CMAQ_2016ff_cb6r3_16j_12US2 O3_8hrmax for AQS_Daily_O3 Site: 490495010 in UT



# Beta MDA8 Ozone Time Series – Gothic, CO

CMAQ_2016ff_cb6r3_16j_12US2 O3_1hrmax for CASTNET_Daily Site: GTH161 in CO




Bias: +2%

Error: 10%

Correlation: 0.41