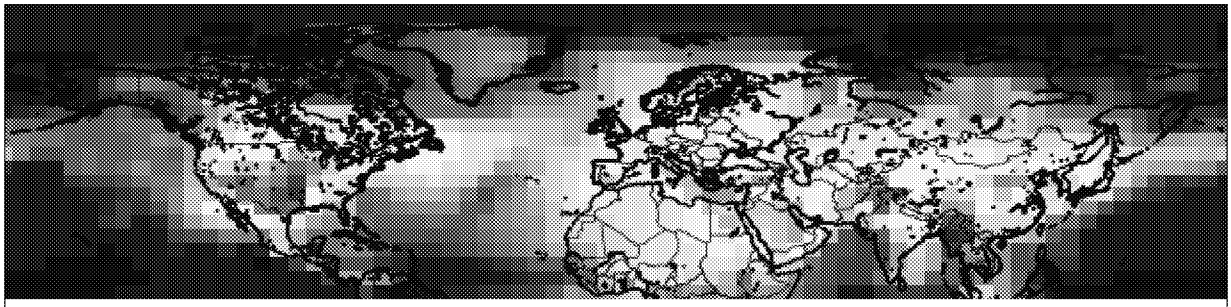


# TASK F-3: ANALYSIS OF THE CONTRIBUTION OF INTERNATIONAL EMISSIONS TO DENVER OZONE CONCENTRATIONS

Ramboll Environ
Alpine Geophysics

DRAFT

Revised June 30, 2017

## TASK F-3: ANALYSIS OF INTERNATIONAL CONTRIBUTIONS

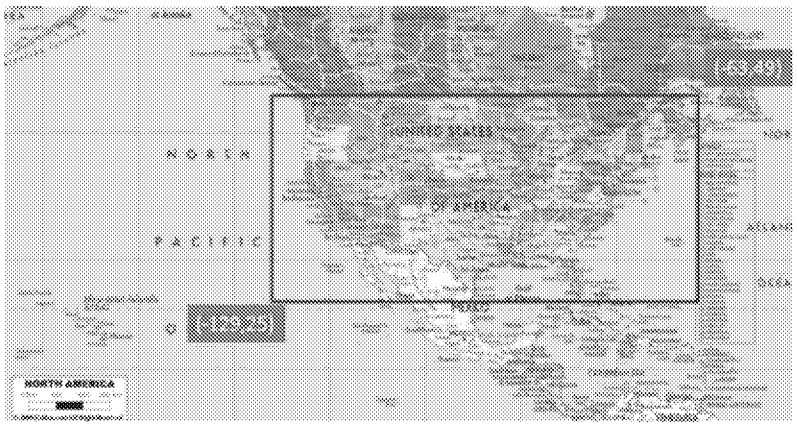
- Objective: To assess ozone levels in the DM/NFR NAA without the contributions of non-U.S. international anthropogenic emissions
- Purpose:
  - To determine the contributions of international anthropogenic emissions outside of the U.S. has on ozone and ozone Design Values (DVs) in the DM/NFR NAA
  - Related to Section 179B of Clean Air Act (CAA) that allows states to demonstrate they are in attainment of the Ozone NAAQS but for international contributions:
    - § 179B(b): ATTAINMENT OF OZONE LEVELS.—Notwithstanding any other provision of law, any State that establishes to the satisfaction of the Administrator that, with respect to an ozone nonattainment area in such State, such State would have attained the national ambient air quality standard for ozone by the applicable attainment date, but for emissions emanating from outside of the United States, shall not be subject to the provisions of section 181(a)(2) or (5) or section 185.

## APPROACH FOR INTERNATIONAL CONTRIBUTIONS

- GEOS-Chem global chemistry model simulations for 2011 base case
  - Process 2011 GEOS-Chem output to generate Boundary Conditions (GCBC) for CAMx 36 km CONUS domain
- CAMx 2011 36 km/12 km (CONUS/WESTUS) base case simulation using GCBC
  - CAMx 12 km 2011 GCBC base case ozone model performance evaluation (MPE) in the DM/NFR NAA and comparison with the previous CAMx 2011 12 km MOZART global chemistry model BC (MZBC) base case results
- GEOS-Chem 2011 simulation with no non-U.S. international anthropogenic emissions
  - Process 2011 GEOS-Chem no international anthropogenic emissions for CAMx 36 km BCs
- CAMx 2011 36 km/12 km simulations with no non-U.S. anthropogenic emissions
  - BCs from GEOS-Chem no international anthro run plus zero-out Mex/Can anthro emissions in 36 km CONUS domain
- Calculation of DM/NFR NAA 2011 ozone DVs without non-U.S. anthro emissions
- Document in PowerPoint Presentations

## GEOS-CHEM APPROACH FOR NO NON-U.S. INTERNATIONAL ANTHROPOGENIC EMISSION CONTRIBUTIONS

- Turn off all countries anthropogenic emissions except for U.S.
- For shipping and aircraft emissions that are not associated with a country, remove emissions outside of red box

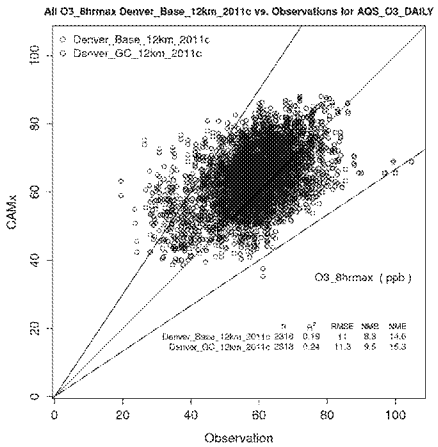


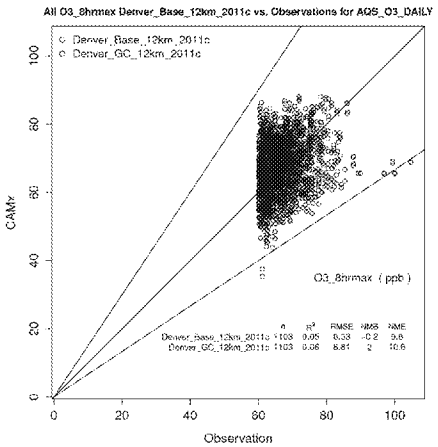
## NEW CAMX 2011 36/12 KM GCBC BASE CASE

- Compare CAMx 2011 GCBC ozone model performance evaluation (MPE) with previous CAMx 36/12 km base case that used boundary conditions based on MOZART global chemistry model (MZBC)
- Numerous MPE comparisons using AMET were generated
- A few examples follow

# CAMX 12 KM BASE (MZBC) AND GCBC AQS MDA8 OZONE

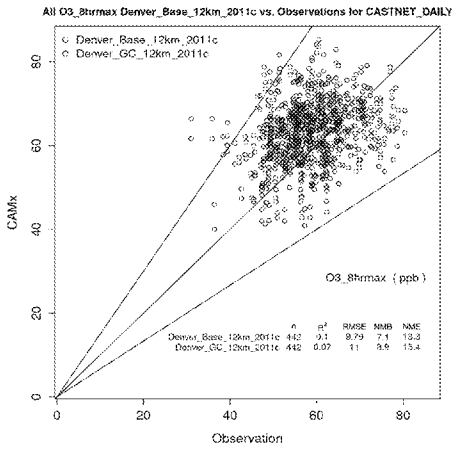
- No Ozone Cut-Off: Bias = 8.3% (MZBC) and 9.5% (GCBC) [Goal ≤±15%]
- 60 ppb Ozone Cut-Off: Bias = -0.2% (MZBC) and 2.0% (GCBC) [Goal ≤±15%]

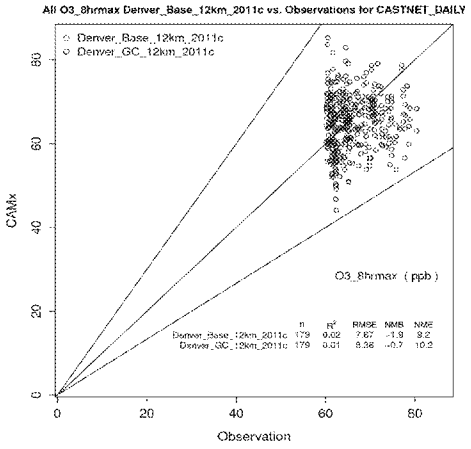


# CAMX 12 KM BASE (MZBC) AND GCBC CASTNET MDA8 OZONE

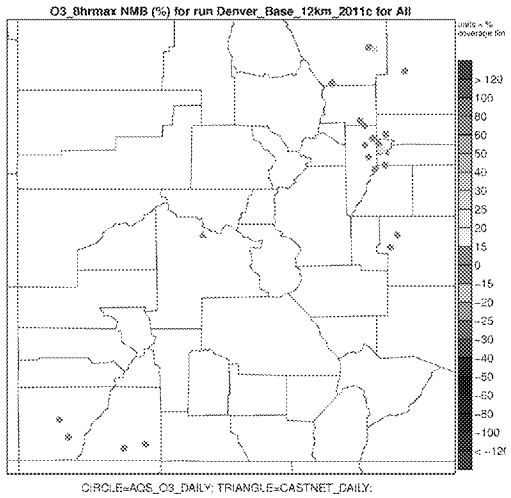
- No Ozone Cut-Off: Bias = 7.1% (MZBC) and 8.9% (GCBC) [Goal ≤±15%]
- 60 ppb Ozone Cut-Off: Bias = -1.9% (MZBC) and -0.7% (GCBC) [Goal ≤±15%]



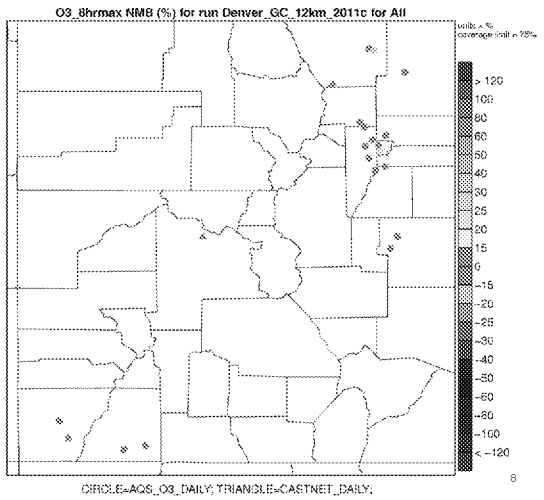



# SITE-SPECIFIC NORMALIZED MEAN BIAS MDA8 ALL DAYS

MZBC

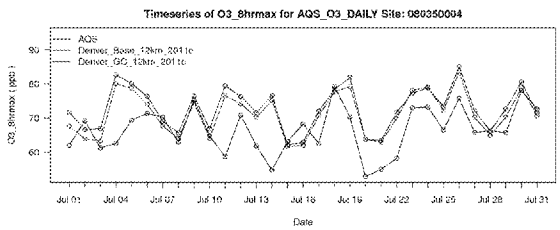


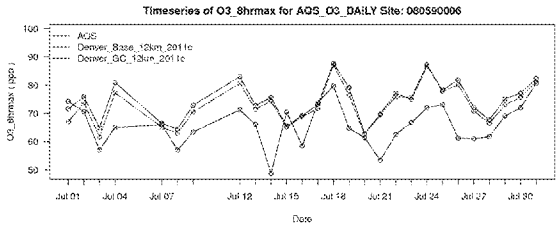

GCBC

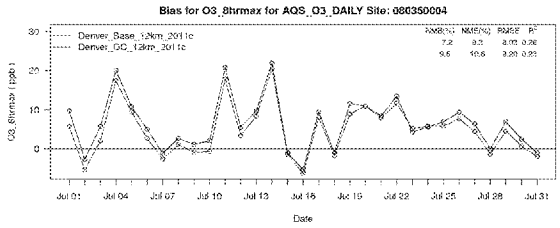


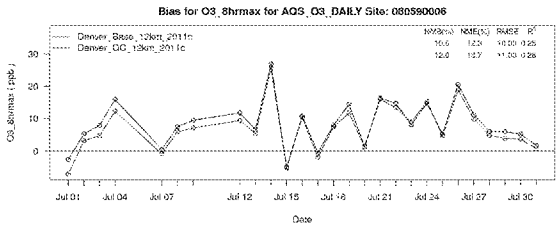
# MDA8 OZONE JUL @ CHAT (LEFT) AND RFNO (RIGHT)

- CHAT: Bias = 7.2% (MZBC) and 9.6% (GCBC) [Goal ≤±15%]
- RFNO: Bias = 10.6% (MZBC) and 12.8% (GCBC) [Goal ≤±15%]

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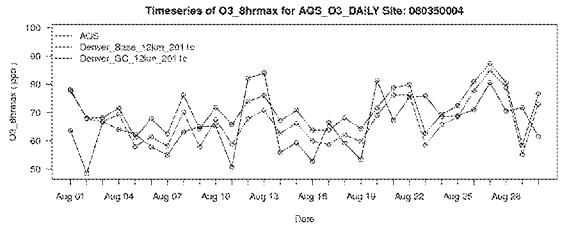
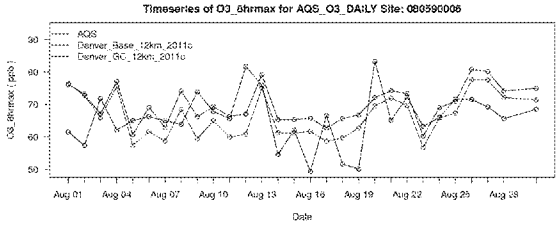
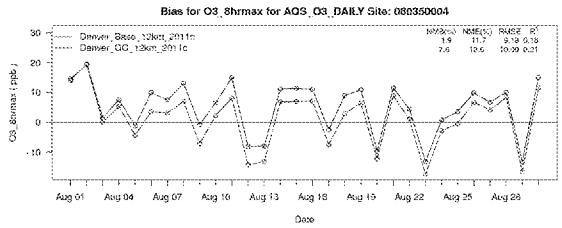
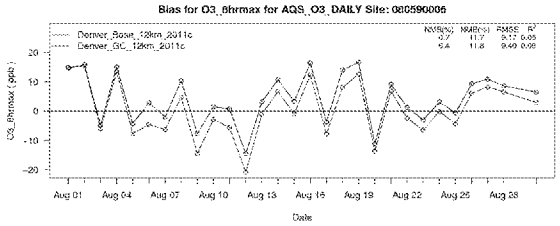
# MDA8 OZONE AUG @ CHAT (LEFT) AND RFNO (RIGHT)

- CHAT: Bias = 1.9% (MZBC) and 7.8% (GCBC) [Goal ≤±15%]
- RFNO: Bias = 0.7% (MZBC) and 6.4% (GCBC) [Goal ≤±15%]



## OVERALL MDA8 OZONE MPE – ALL DATA

- CAMx GCBC higher than MZBC by 0.7 ppb on average
  - Since MZBC overestimated a little, GCBC stats slightly worse
- NMB/FB bias for MZBC (+7.1% to +8.8%) and GCBC (+8.6% to +9.9%) within ozone performance goals (≤±15%)
- NME/FE error for MZBC (11.4%-14.6%) and GCBC (13.1%-15.0%) well within ozone performance goals (≤35%)

| | # | Avg Obs | Avg Mod | Max Obs | Max Mod | Corr | MB | ME | NMB | NME | FB | FE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **AOS** | | | | | | | | | | | | |
| **MZBC** | 2318 | 59.0 | 63.9 | 105.0 | 88.1 | 0.44 | 4.9 | 8.6 | 8.3 | 11.9 | 8.8 | 14.6 |
| **GCBC** | 2318 | 59.0 | 64.6 | 105.0 | 88.0 | 0.49 | 5.6 | 9.0 | 9.6 | 13.1 | 9.6 | 15.0 |
| **CASTNet** | | | | | | | | | | | | |
| **MZBC** | 442 | 58.6 | 62.7 | 80.4 | 84.1 | 0.31 | 4.1 | 7.8 | 7.6 | 11.4 | 7.1 | 12.9 |
| **GCBC** | 442 | 58.6 | 63.8 | 80.4 | 85.2 | 0.26 | 5.2 | 9.0 | 9.9 | 13.9 | 8.6 | 14.8 |

## OVERALL MDA8 OZONE MPE – 60 PPB CUT-OFF

- CAMx GCBC performance slightly worse but comparable to MZBC
- NMB/FB bias for MZBC (-2.1% to +0.2%) and GCBC (-1.0% to +2.8%) within ozone performance goals (≤±15%)
- NME/FE error for MZBC (7.2-9.8%) and GCBC (9.2-10.5%) well within ozone performance goals (≤35%)

| | # | Avg Obs | Avg Mod | Max Obs | Max Mod | Corr | MB | ME | NMB | NME | FB | FE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **AOS** | | | | | | | | | | | | |
| **MZBC** | 1103 | 67.0 | 66.9 | 105.0 | 88.1 | 0.23 | -0.1 | 6.6 | 0.2 | 8.5 | -0.5 | 9.8 |
| **GCBC** | 1103 | 67.0 | 68.4 | 105.0 | 88.0 | 0.24 | 1.3 | 7.1 | 2.8 | 9.5 | 1.6 | 10.5 |
| **CASTNet** | | | | | | | | | | | | |
| **MZBC** | 179 | 66.2 | 64.9 | 80.4 | 83.6 | 0.13 | -1.3 | 6.1 | -1.5 | 7.2 | -2.1 | 9.3 |
| **GCBC** | 179 | 66.2 | 65.7 | 80.4 | 85.2 | 0.09 | -0.4 | 6.7 | -0.3 | 9.2 | -1.0 | 10.2 |

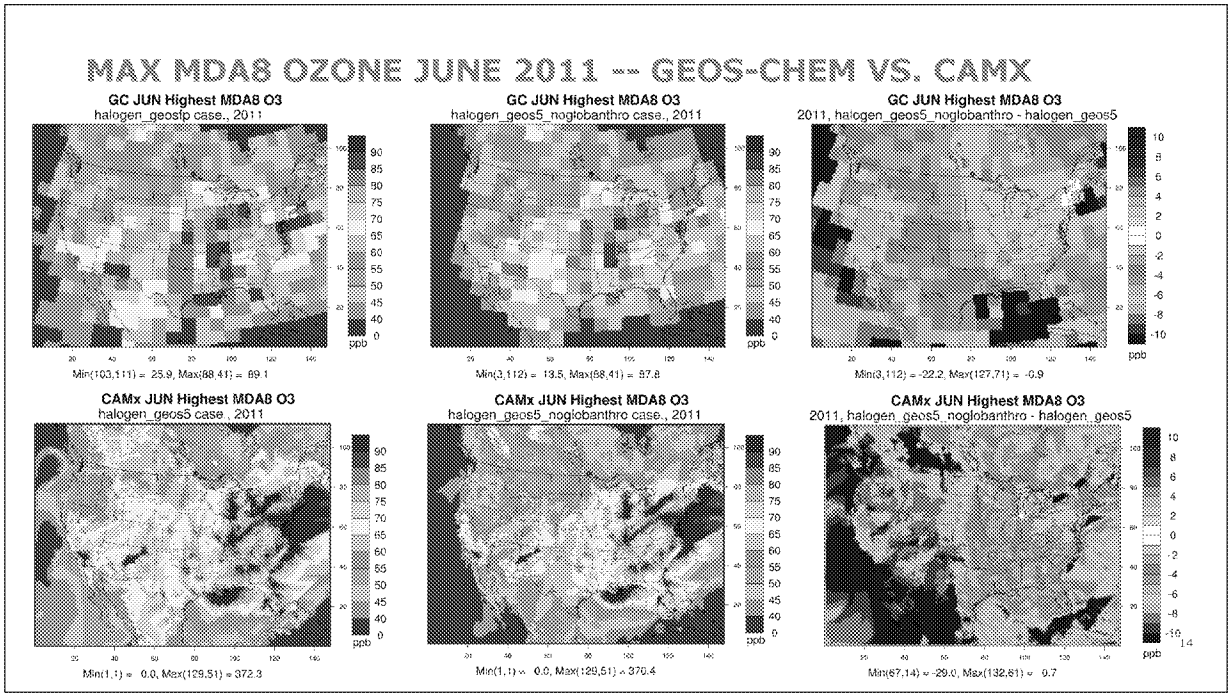
## CAMX VS GEOS-CHEM 2011 MODEL COMPARISON

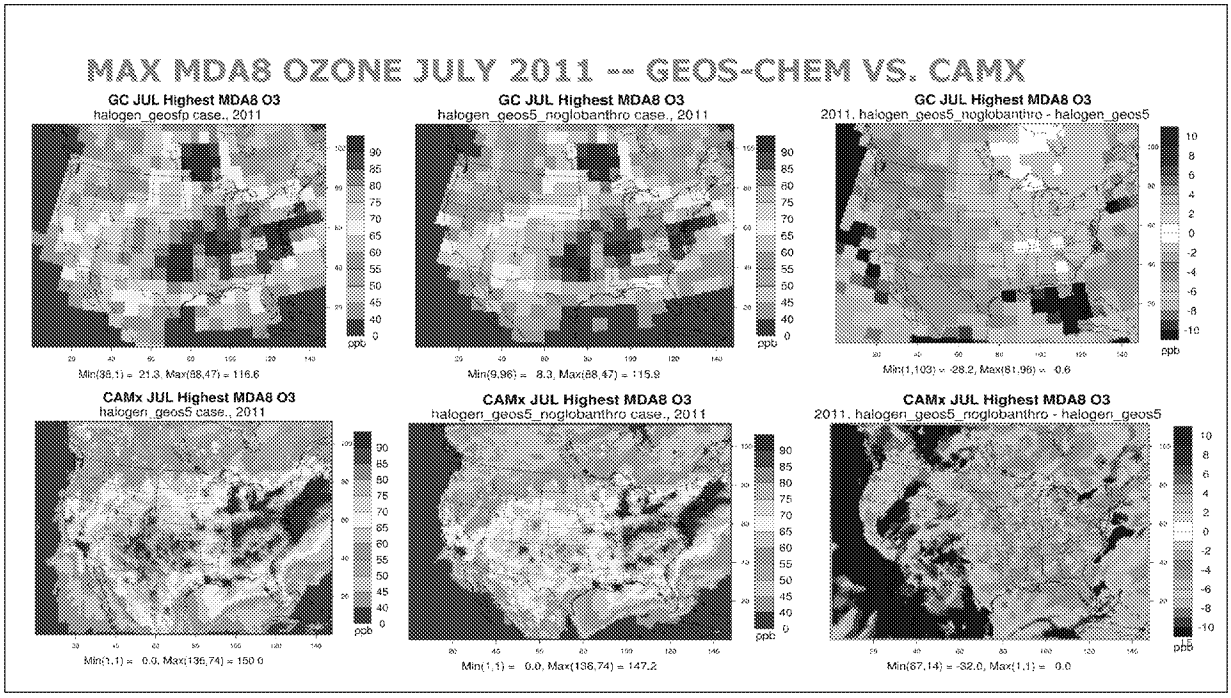
- CAMx v6.20 (March, 2015)
- 36 km CONUS and 12 km WESTUS domains
- 25 vertical layers to region top of 50 mb (~19 km MSL)
  - 16 layers below ~3,000 m
- CB6r2 chemical mechanism
- RADM aqueous-phase chemistry
- ISORROPIA aerosol thermodynamics

- GEOS-Chem v10.01 (June, 2015)
- Global Modeling Domain
- 2.0 x 2.5 degree (~200 km)
- 72 vertical Layers to region top of 0.01 mb (~ 80 km MSL)
  - 17 Layers below ~3,000 m
- Benchmark chemistry simulation
  - Troposphere: JPL 10-6 chemical kinetics mechanism with additional SOA chemistry scheme
  - Stratosphere: Universal tropospheric-stratospheric chemistry (UCX) extension
- FAST-JX radiative transfer algorithm
- ISORROPIA aerosol thermodynamics



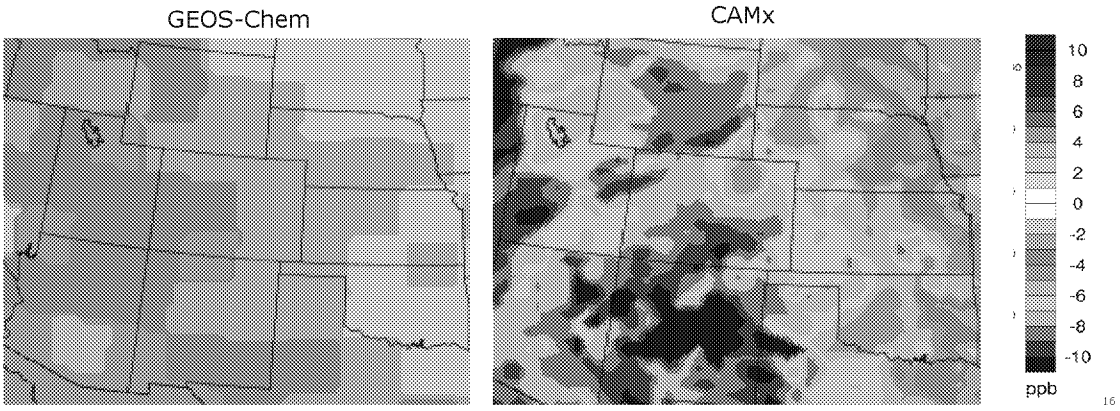
UCX = Universal stratospheric chemistry mechanism


MAX MDA8 OZONE JUNE 2011 -- GEOS-CHEM VS. CAMX
GC JUN Highest MDA8 O3
halogen_geosfp case., 2011
Min(103,111) = 25.9, Max(88,41) = 89.1
GC JUN Highest MDA8 O3
halogen_geos5_noglobanthro case., 2011
Min(3,112) = 13.5, Max(68,41) = 87.8
GC JUN Highest MDA8 O3
2011, halogen_geos5_noglobanthro - halogen_geos5
Min(3,112) = -22.2, Max(127,71) = -0.9
CAMx JUN Highest MDA8 O3
halogen_geos5 case., 2011
Min(1,1) = 0.0, Max(129,51) = 372.3
CAMx JUN Highest MDA8 O3
halogen_geos5_noglobanthro case., 2011
Min(1,1) = 0.0, Max(129,51) = 370.4
CAMx JUN Highest MDA8 O3
2011, halogen_geos5_noglobanthro - halogen_geos5
Min(67,14) = -29.0, Max(132,81) = 0.7
ppb


MAX MDA8 OZONE JULY 2011 -- GEOS-CHEM VS. CAMX
GC JUL Highest MDA8 O3
halogen_geosfp case., 2011
Min(38,1) = 21.3, Max(88,47) = 116.6
GC JUL Highest MDA8 O3
halogen_geos5_noglobanthro case., 2011
Min(9,96) = 8.3, Max(88,47) = 115.9
GC JUL Highest MDA8 O3
2011, halogen_geos5_noglobanthro - halogen_geos5
Min(1,103) = -28.2, Max(81,98) = 0.6
CAMx JUL Highest MDA8 O3
halogen_geos5 case., 2011
Min(1,1) = 0.0, Max(136,74) = 150.0
CAMx JUL Highest MDA8 O3
halogen_geos5_noglobanthro case., 2011
Min(1,1) = 0.0, Max(136,74) = 147.2
CAMx JUL Highest MDA8 O3
2011, halogen_geos5_noglobanthro - halogen_geos5
Min(87,14) = -32.0, Max(1,1) = 0.0
ppb

## MAX MDA8 OZONE JULY 2011 -- GEOS-CHEM VS. CAMX

- Within Colorado, change in maximum MDA8 ozone in July:
  - 1-6 ppb GEOS-Chem (~200 km) and 3-11 ppb CAMx (12 km)
  - Ozone contribution of international anthropogenic emissions in CAMx ~2x GEOS-Chem

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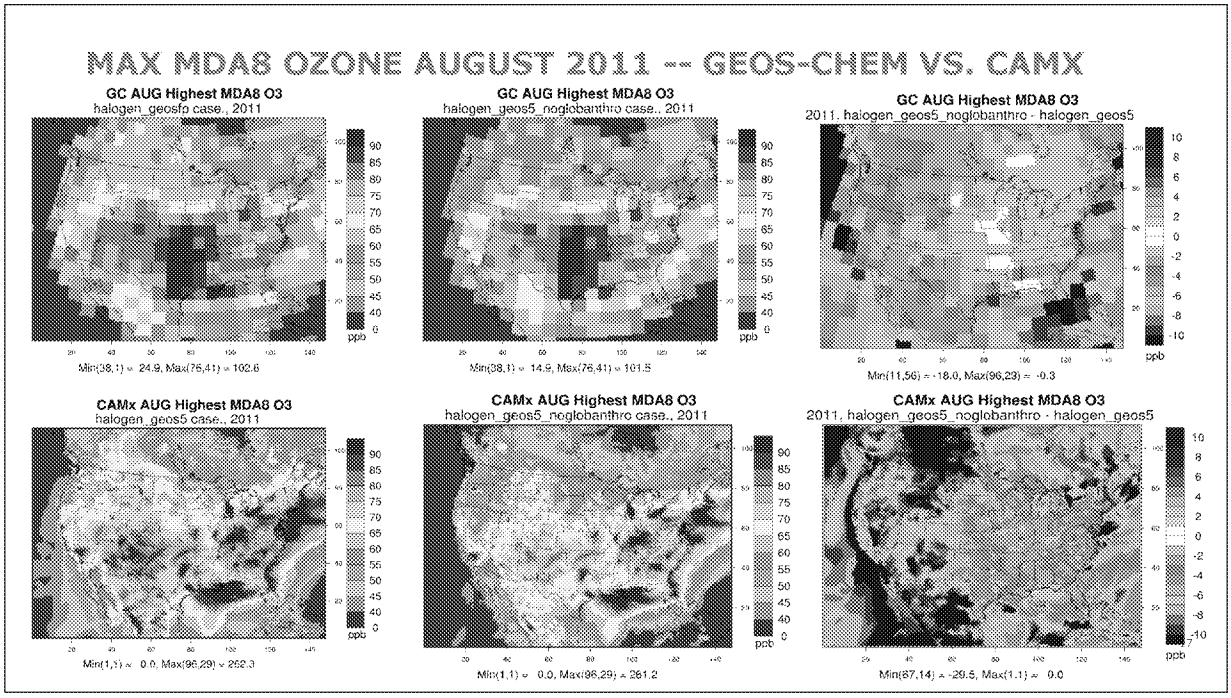

MAX MDA8 OZONE AUGUST 2011 -- GEOS-CHEM VS. CAMX
GC AUG Highest MDA8 O3
halogen_geosfp case., 2011
Min(38,1) = 24.9, Max(76,41) = 102.6
GC AUG Highest MDA8 O3
halogen_geos5_noglobanthro case., 2011
Min(38,1) = 14.9, Max(76,41) = 101.5
GC AUG Highest MDA8 O3
2011, halogen_geos5_noglobanthro - halogen_geos5
Min(11,56) = -18.0, Max(96,29) = -0.3
CAMx AUG Highest MDA8 O3
halogen_geos5 case., 2011
Min(1,1) = 0.0, Max(96,29) = 252.3
CAMx AUG Highest MDA8 O3
halogen_geos5_noglobanthro case., 2011
Min(1,1) = 0.0, Max(96,29) = 261.2
CAMx AUG Highest MDA8 O3
2011, halogen_geos5_noglobanthro - halogen_geos5
Min(87,14) = -29.5, Max(1,1) = 0.0
ppb

# OZONE DESIGN VALUES

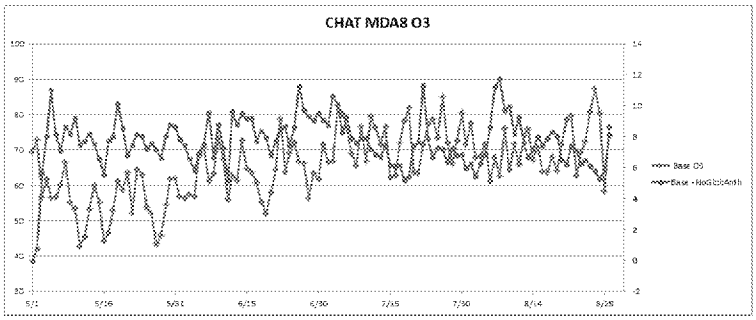
- Run MATS with CAMx 12 km GCBC and No Intl Anthro as BY and FY modeling results
- Non-U.S. anthropogenic emissions contribute from 5.2 to 7.2 ppb to 2009-2013 ozone DVs in DM/NFR NAA and surrounding areas
  - At four key monitoring sites (CHAT, RFNO, NREL & FTCW) contributes 6.1 to 6.6 ppb
- Maximum 2009-2013 ozone DVs w/o non-U.S. international anthropogenic emissions is 74.1 ppb at CHAT
  - "But for" non-U.S. anthropogenic emissions, the DM/NFR NAA would have attained the 2008 75 ppb ozone NAAQS

| Site ID | Site | County | DVC | NoIntl | Diff |
|---|---|---|---|---|---|
| 80350004 | CHAT | Douglas | 80.7 | 74.1 | 6.6 |
| 80590006 | RFNO | Jefferson | 80.3 | 73.9 | 6.4 |
| 80590011 | NREL | Jefferson | 78.7 | 72.3 | 6.4 |
| 80690011 | FTCW | Larimer | 78.0 | 71.9 | 6.1 |
| 81030006 | RANG | Rio Blanco | 77.0 | 68.8 | 8.2 |
| 80050002 | HIGH | Arapahoe | 76.7 | 70.3 | 6.4 |
| 80013001 | WELB | Adams | 76.0 | 69.9 | 6.1 |
| 80590005 | WELC | Jefferson | 75.7 | 69.4 | 6.3 |
| 80690007 | RMNP | Larimer | 75.7 | 69.7 | 6.0 |
| 80130011 | SOBC | Boulder | 74.7 | 68.6 | 6.1 |
| 81230009 | WELD | Weld | 74.7 | 68.9 | 5.8 |
| 80590013 | ASPN | Jefferson | 74.5 | 68.6 | 5.9 |
| 80590002 | ARVA | Jefferson | 74.0 | 68.0 | 6.0 |
| 80050006 | AURE | Arapahoe | 73.5 | 67.3 | 6.2 |
| 80671004 | WEMI | La Plata | 73.0 | 66.2 | 6.8 |
| 80410016 | MANI | El Paso | 72.7 | 66.4 | 6.3 |
| 80310014 | CARR | Denver | 71.0 | 65.3 | 5.7 |
| 80410013 | ACAD | El Paso | 71.0 | 65.0 | 6.0 |
| 80690012 | RIST | Larimer | 71.0 | 65.4 | 5.6 |
| 80677001 | DNGO | La Plata | 68.7 | 62.3 | 6.4 |
| 80691004 | FTCO | Larimer | 68.7 | 63.5 | 5.2 |
| 80830101 | MEVE | Montezuma | 68.3 | 61.7 | 6.6 |
| 80830006 | CORT | Montezuma | 67.3 | 60.6 | 6.7 |
| 80770020 | PALI | Mesa | 67.0 | 59.8 | 7.2 |
| 80310025 | DASH | Denver | 65.0 | 59.5 | 5.5 |
| 80450012 | RIFL | Garfield | 65.0 | 58.9 | 6.1 |
| 81030005 | MEEK | Rio Blanco | 63.5 | 57.3 | 6.2 |

# EFFECTS OF INTERNATIONAL ANTHROPOGENIC EMISSIONS ON MDA8 OZONE CONCENTRATIONS IN THE DM/NFR NAA

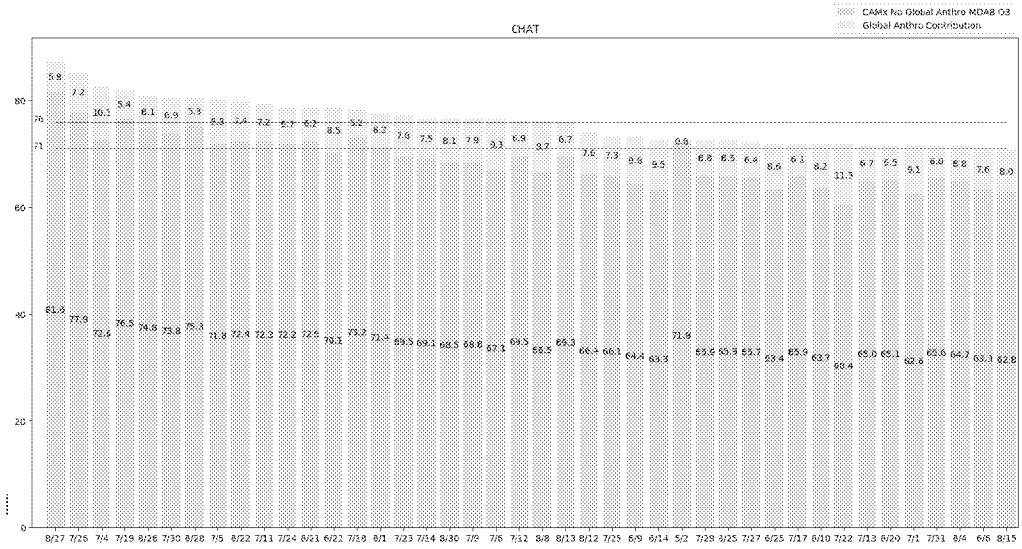
- Extract MDA8 ozone concentrations from CAMX 2011 base and no international anthropogenic emissions simulations at DM/NFR monitoring sites
- Do the same for GEOS-Chem 2011 base and no international anthropogenic emissions
- Prepare displays of non-U.S. global anthropogenic emissions contribution to MDA8 ozone at key monitoring sites.

- Example CAMx results for MDA8 ozone at Chatfield
  - CAMx 2011 base total ozone (left axis)
  - CAMx 2011 international anthropogenic contribution (right axis)



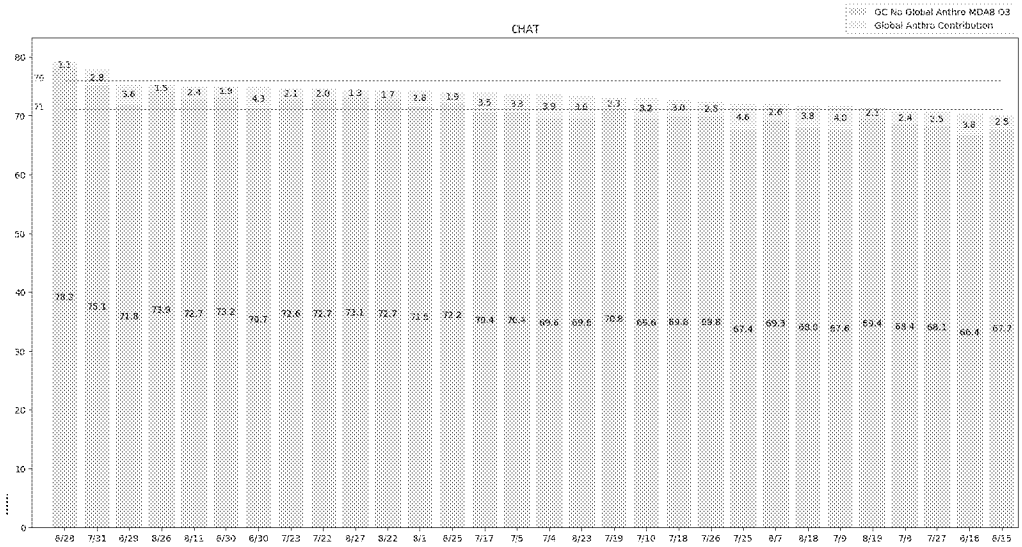
# CAMX MDA8 OZONE CONTRIBUTIONS AT CHAT

## RANKED FOR DAYS WITH MDA8 OZONE > 70 PPB



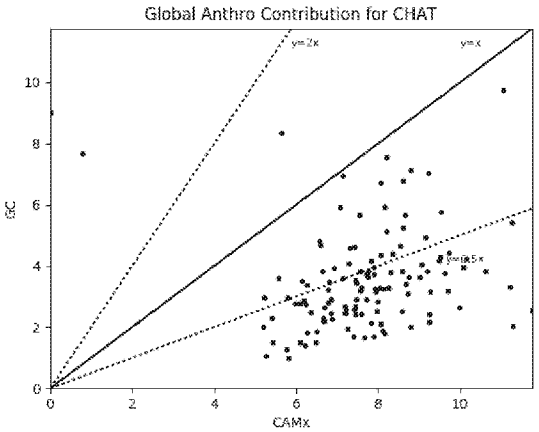
# GEOS-CHEM MDA8 OZONE CONTRIBUTIONS AT CHAT

## RANKED FOR DAYS WITH MDA8 OZONE > 70 PPB

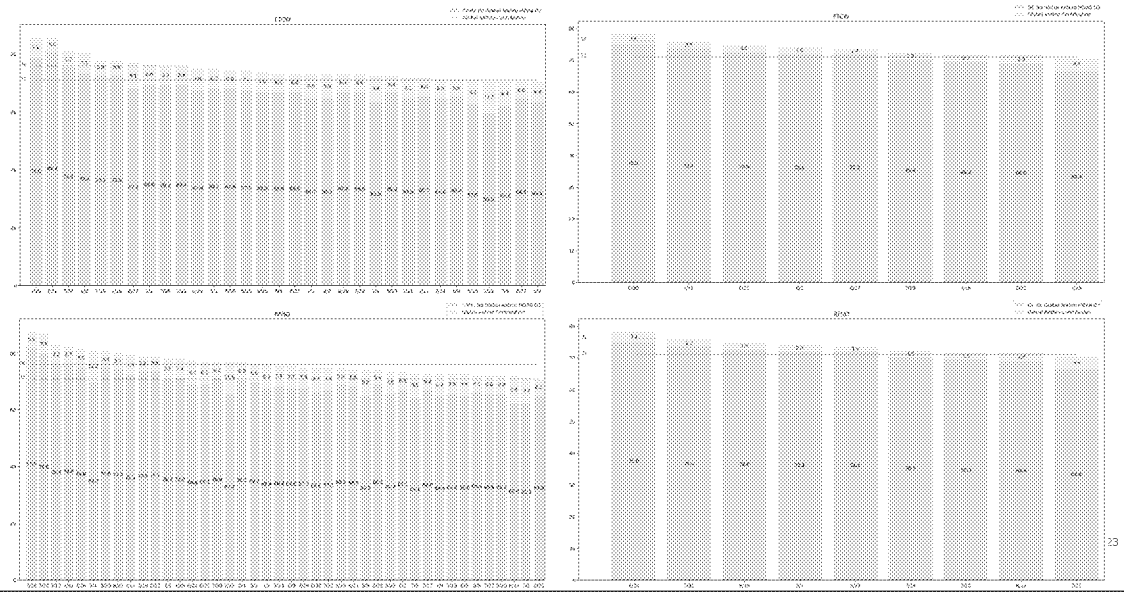


# CAMX VS. GEOS-CHEM GLOBAL ANTHROPOGENIC CONTRIBUTION TO MDA8 OZONE AT CHAT

- CAMx global anthropogenic contribution ~2x GEOS-Chem
- Consistent with spatial maps presented previously
- Reasons why GEOS-Chem international anthropogenic contributions is lower not clear
  - Likely related to coarse grid resolution used in GEOS-Chem (~200 km)
  - Reduced vertical transport
    - GEOS-Chem fails to see full terrain effects that can generate higher vertical transport

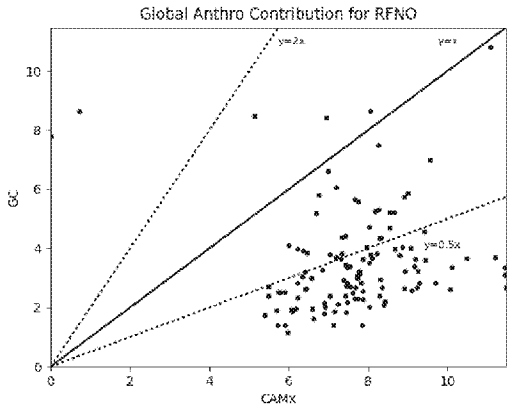


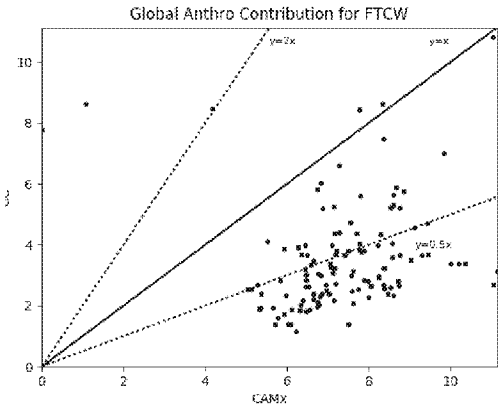
## CAMX (LEFT) VS. GEOS-CHEM (RIGHT) FTCW (TOP) RFNO (BOTTOM)
## RANKED FOR DAYS WITH MDA8 OZONE > 70 PPB



# CAMX VS. GEOS-CHEM GLOBAL ANTHROPOGENIC CONTRIBUTION TO MDA8 OZONE AT RFNO AND FTCW

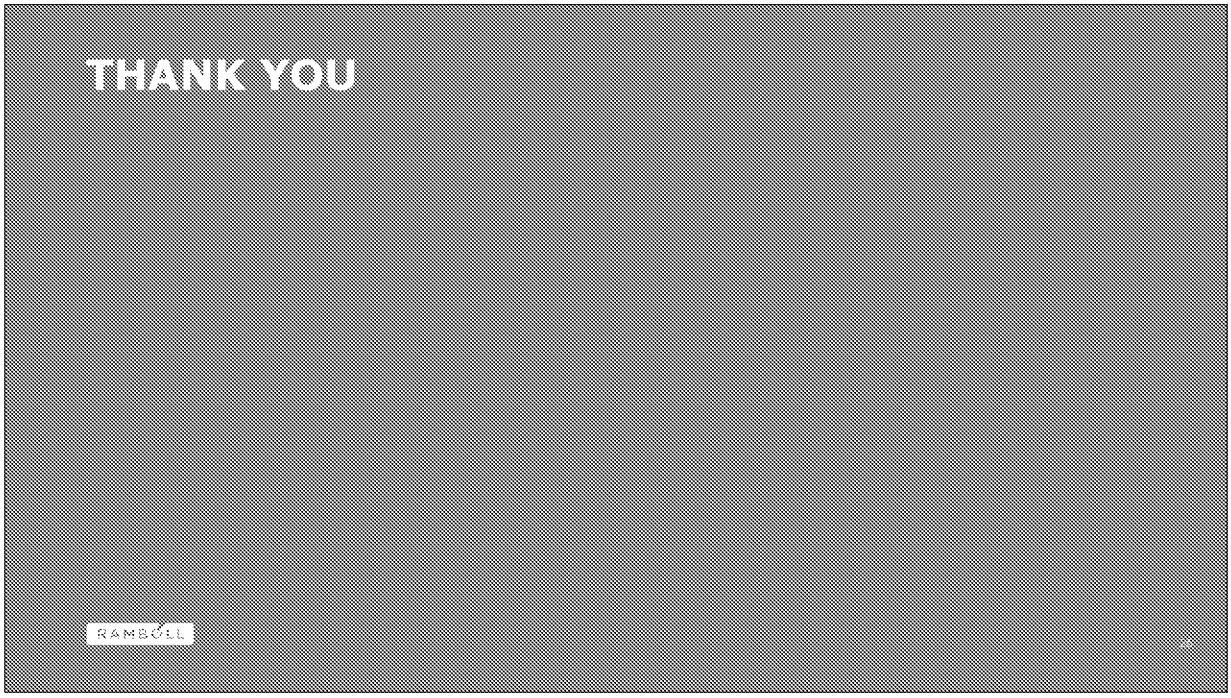
- With the exception of four days, CAMx Intl Anthro > GEOS-Chem by on average ~2x



## CONCLUSIONS: TASK F-3: CONTRIBUTIONS OF INTERNATIONAL EMISSIONS

- Both CAMx 2011 12 km MZBC and GCBC base case simulations achieves ozone model performance goals
  - GCBC run slightly (~1 ppb) higher ozone (~1-2 percentage point in the bias) than MZBC
- CAMx contributions of non-U.S. anthropogenic emissions to 2009-2013 average ozone DVs is ~6 ppb (5.2 – 8.2 ppb)
  - Would expect a similar level of reduction in 2017
- Removal of international anthropogenic emissions reduces the maximum 2009-2013 average ozone DV from 80.7 ppb to 74.1 ppb, which attains the 2008 ozone NAAQS
  - Maximum current (2014-2016) observed ozone DV in the DM/NFR NAA is 80 ppb (NREL); if reduced by 6 ppb due to the removal of international anthropogenic emissions it would be 74 ppb and attain the 2008 ozone NAAQS
- CAMx estimates approximately twice the reduction in MDA8 ozone in the DM/NFR NAA (average ~ 7 ppb) than GEOS-Chem (average ~ 3.5 ppb) due to the elimination of international anthropogenic emissions

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