# Interpreting Background Ozone

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MARAMA Science Meeting: July 29, 2015

# Presentation Topics

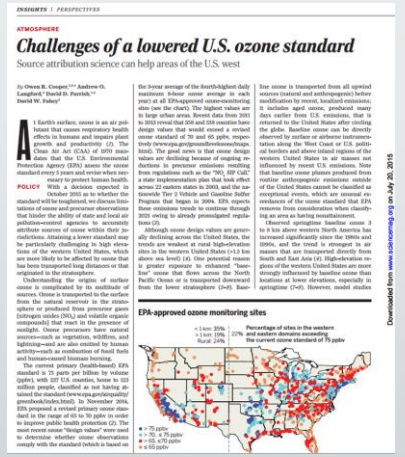
- Overview of background ozone
- Evolution of background ozone analyses
- EPA modeling of background ozone for $O_3$ NAAQS review
  - Model description and evaluation
  - Estimates of background by type (natural vs. USB)
  - Estimates of background ozone by location (EUS vs. WUS)
  - Estimates of mean background ozone vs. high-day background ozone
  - Model diagnostic analyses
  - Comparisons against other $BGO_3$ modeling analyses
- Future EPA modeling plans to improve background ozone estimates

# Overview of background ozone (1 of 2)

- It can be challenging to constructively discuss the components and implications of background ozone ($BGO_3$) for a variety of reasons
  - Definitions of $BGO_3$ can vary.
  - The impacts of $BGO_3$ can vary across space and time.
  - $BGO_3$ can be generated by a variety of processes.
  - $BGO_3$ is difficult to measure, thus requires AQ models (valuable but imperfect).
  - Multiple CAA provisions address $BGO_3$, but none resolve to everyone's satisfaction.

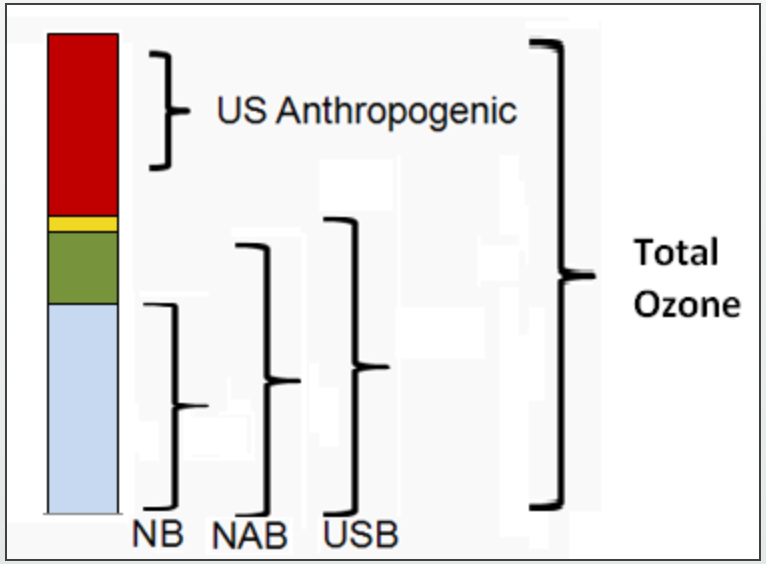
# Overview of background ozone (2 of 2)

- As the NAAQS levels are lowered, importance of $BGO_3$ increases:
  - Are some/all NAAQS violations largely attributable to $BGO_3$?
  - Are some/all NAAQS violations partially attributable to $BGO_3$?
  - Can NAAQS revisions be implemented so that States are not responsible for $BGO_3$ impacts?
  - Will future $BGO_3$ impacts increase making it harder to attain via local/regional controls?
  - What, if anything, can be done about international impacts to improve U.S. air quality?



# EPA definitions of background ozone

- Natural background (NB)
  - Ozone formed from purely natural sources of ozone precursor emissions (vegetation, stratosphere, some fires, some methane, lightning, etc.)
- North American background (NAB) + 
  - NB + ozone formed by manmade sources in countries *outside* N. America.
- U.S. background (USB) + +
  - NB + ozone formed by manmade sources in countries *outside* the U.S.
- Total ozone + + +




***Schematic for instructional purposes only***
*Actual ozone chemistry is non-linear*
*Actual proportions will vary by location*

# Evolution of background ozone analyses (1 of 2)

- After first O3 NAAQS established in 1971, earliest attempts to mitigate the ozone problem in the U.S. focused on local VOC controls.
  - Some progress made but many urban areas failed to meet attainment goals
- This stimulated questions about contribution of "background".
  - $BGO_3$ at that time was considered to be any ozone formed by sources outside the region
  - Prompted numerous observational studies to quantify regional transport impacts
- By the mid 1990's, most ozone control efforts were aimed at reducing regional NOx emissions (and local VOC emissions).
  - Over the past two decades, peak ozone concentrations have improved considerably in the Eastern U.S. and urban parts of California, but less so in rural portions of the Western U.S.

# Evolution of background ozone analyses (2 of 2)

- Initially, background ozone estimates were derived entirely from measurement studies
  - Either by using direct measurements at relatively remote monitoring sites or via inference according to co-located measurements of ozone, NOx, NOy, and CO
- Starting around 2002, AQ modeling analyses began to be completed to estimate impacts of NB, NAB, and/or USB.
  - Typically involved the application of coarse-resolution global models in "zero-out" mode.
- Over time, these analyses became progressively more advanced.
  - Higher resolution global modeling, nested finer-resolution regional modeling
  - Source apportionment modeling began to compliment the zero-out approaches
  - Additional improvements have included: emissions constrained by satellite data, better global emissions inventories, more detailed model evaluation, bias adjustment techniques, multi-model comparisons, etc.

# EPA modeling of background ozone (1 of 2)

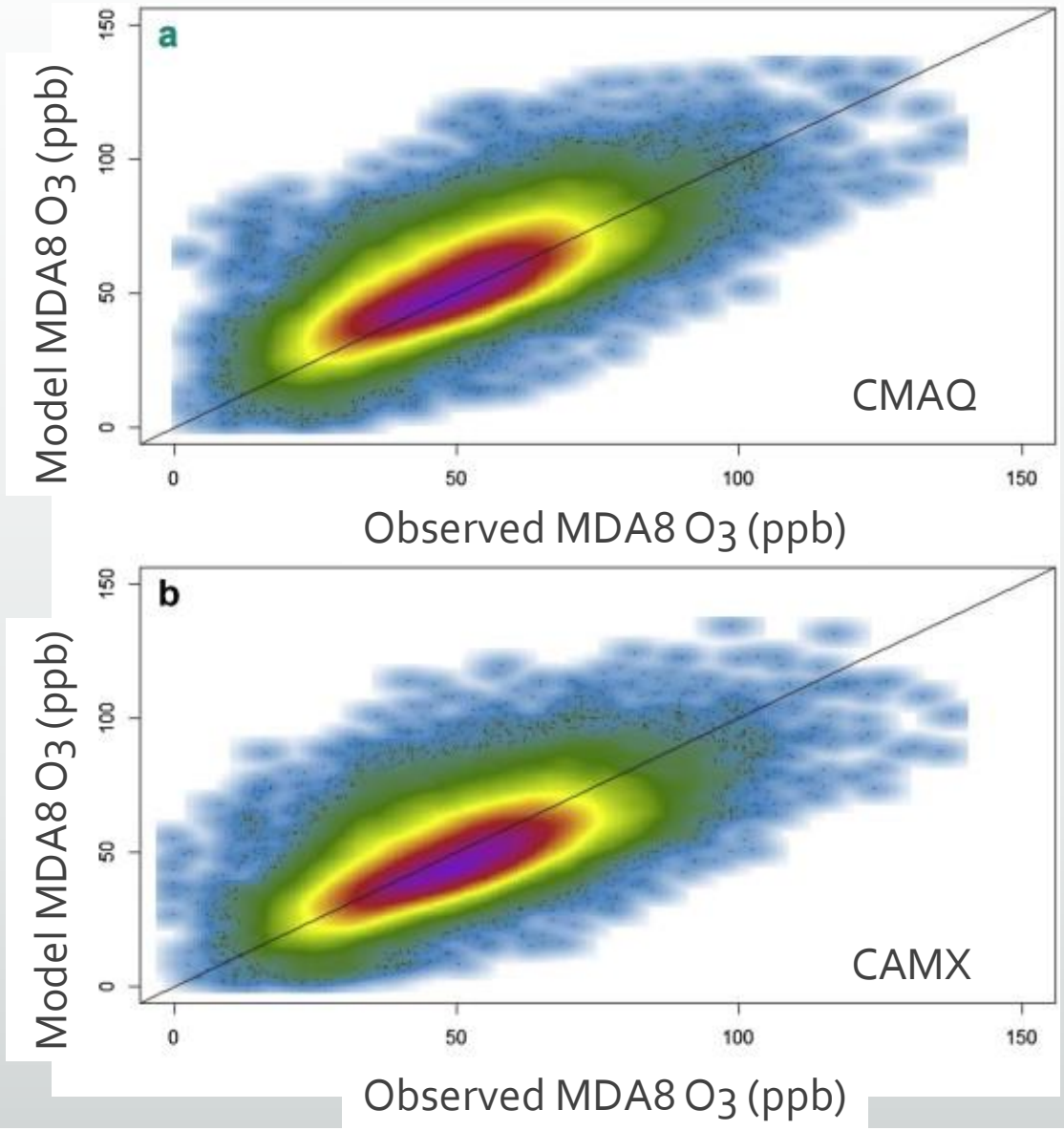
- For the ongoing 2015 O3 NAAQS review, EPA used two separate modeling methodologies to characterize background O3:
  - Model base year = 2007
  - Emissions perturbation (zero out) modeling (GEOS-Chem / CMAQ)
  - Source apportionment modeling (GEOS-Chem / CAMx)
  - Summarized in U.S. EPA (2014) and Dolwick et al. (2015)

- Subsequent source apportionment analysis has been completed for 2011.
  - EPA has also compared background estimates from 2007 against other BGO3 analyses completed elsewhere.

# EPA modeling of background ozone (2 of 2)

- Existing modeling analyses have estimated what $BGO_3$ levels would be in the absence of certain sets of emissions ("zero-out" modeling).
  - NB, NAB, and USB definitions are explicitly tied to zero out modeling.
  - Such analyses are "counterfactual" as manmade emissions do exist.
  - Non-linearities in ozone chemistry, esp. in urban areas, can hinder interpretation.
  - How much ozone would exist in absence of certain emissions sets?
- A separate modeling technique (source apportionment) can estimate the "contribution" of certain sets of emissions.
  - How much existing ozone is due to certain source sectors?

# EPA estimates of model BGO3: model evaluation (1 of 3)



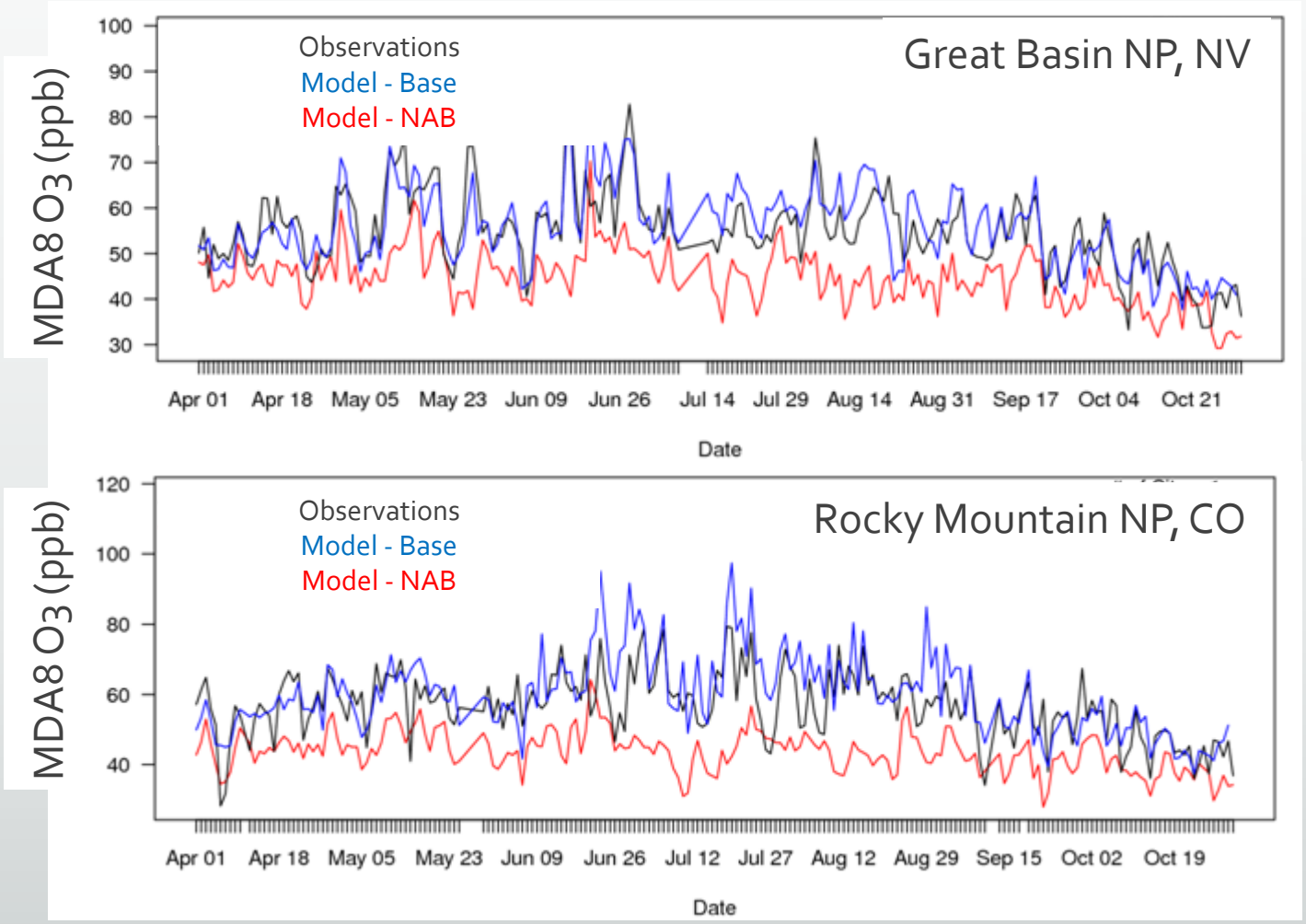

- Over entire domain (Apr-Oct), CMAQ and CAMx MD8O3 values exhibit relatively low bias.
- CAMx ozone is slightly underestimated on average; CMAQ is slight overestimated
  - Both models overestimate low MDA8 O3 and underestimate higher values.

# EPA estimates of model BGO3: model evaluation (2 of 3)

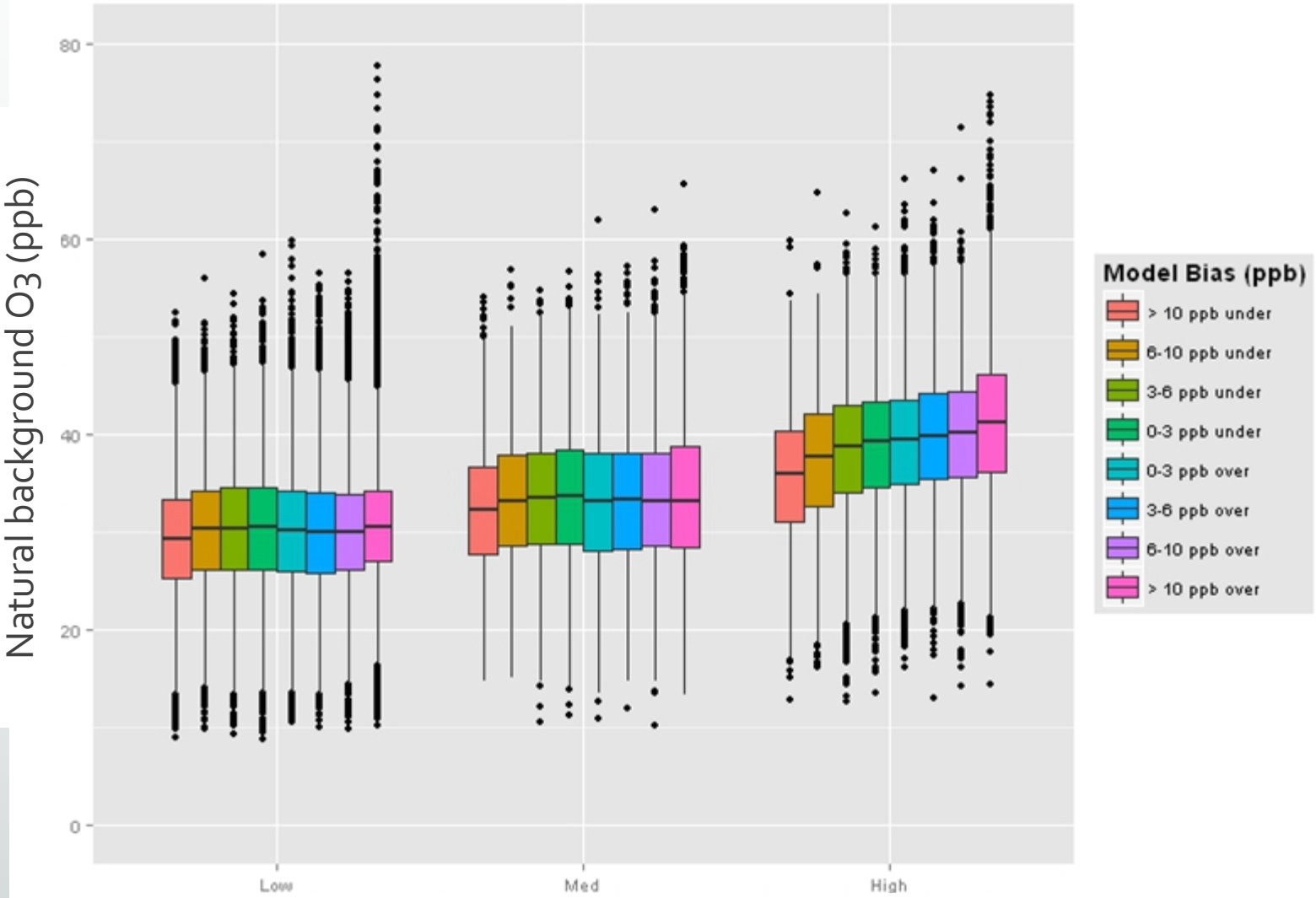
- MDA O3 time series at key background sites suggest model can capture day-to-day variations at these sites
- Slight tendency toward model overestimation of high days at RMNP. These positive biases tend to occur when background contributions are low.

CMAQ

CAMX



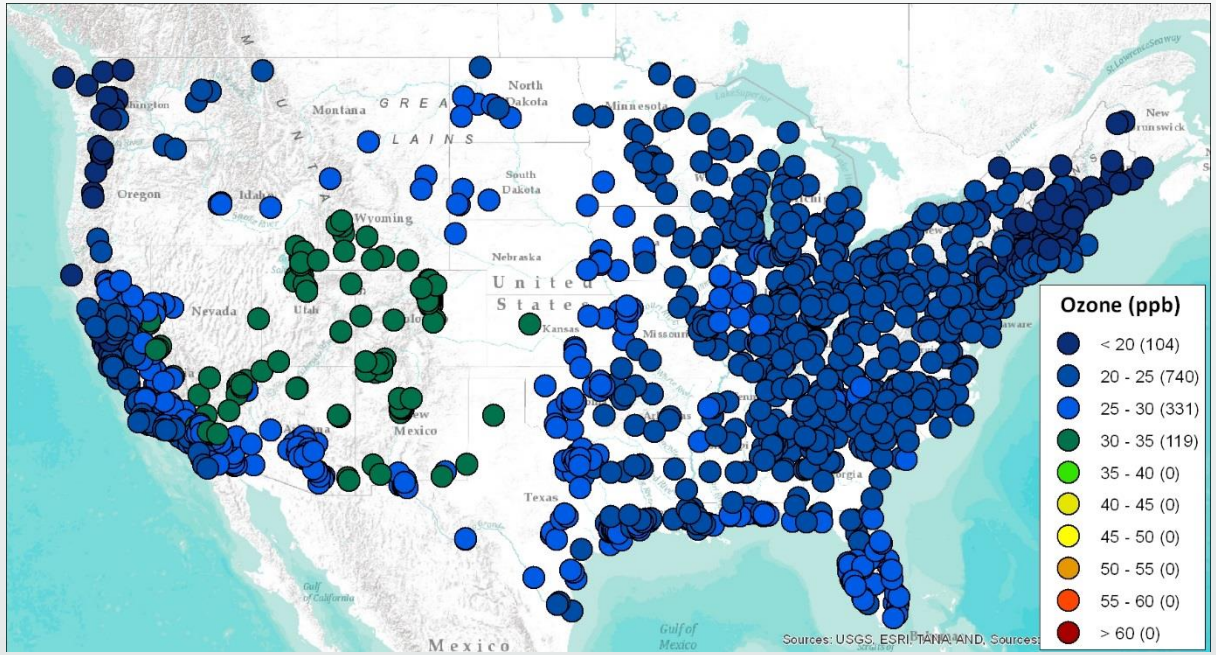
# EPA estimates of model BGO3: model evaluation (3 of 3)



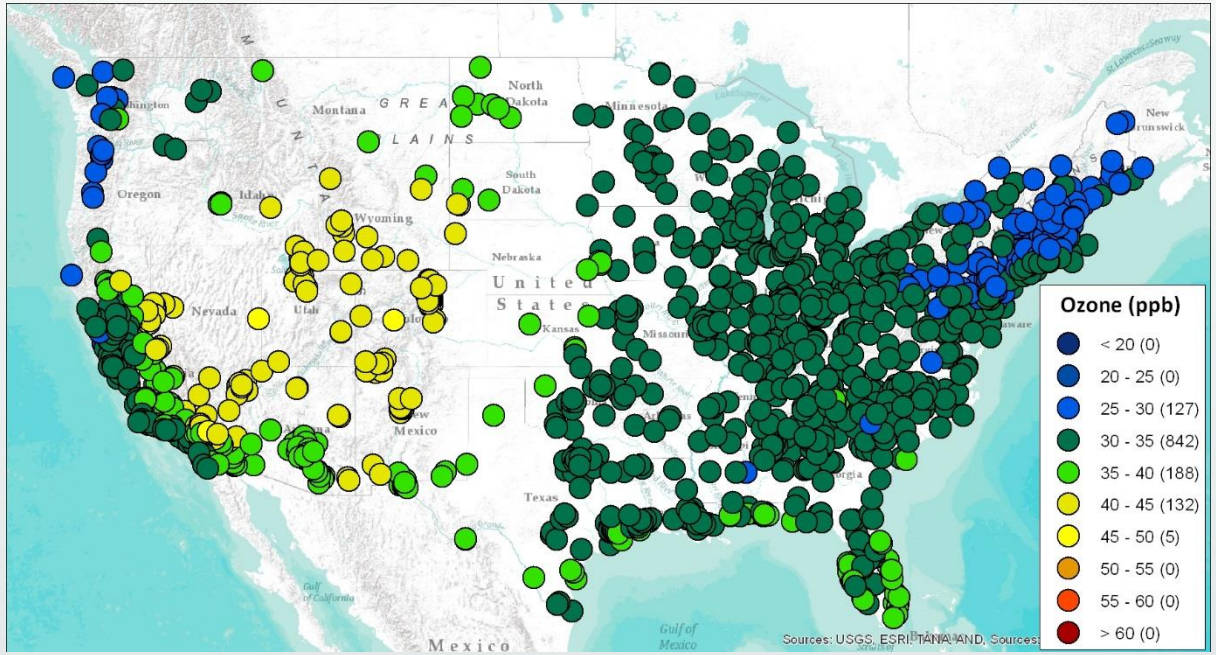

- Operational model evaluations of base case ozone are helpful but cannot isolate model ability to predict background.
- Have attempted to assess by looking how model bias varies by BGO3 estimates.
  - See some correlation between BGO3 estimates and model ozone bias at high elevation sites in the WUS (this may suggest boundaries are overly influencing predictions)

# EPA estimates of model BGO3: Zero out modeling

Natural background



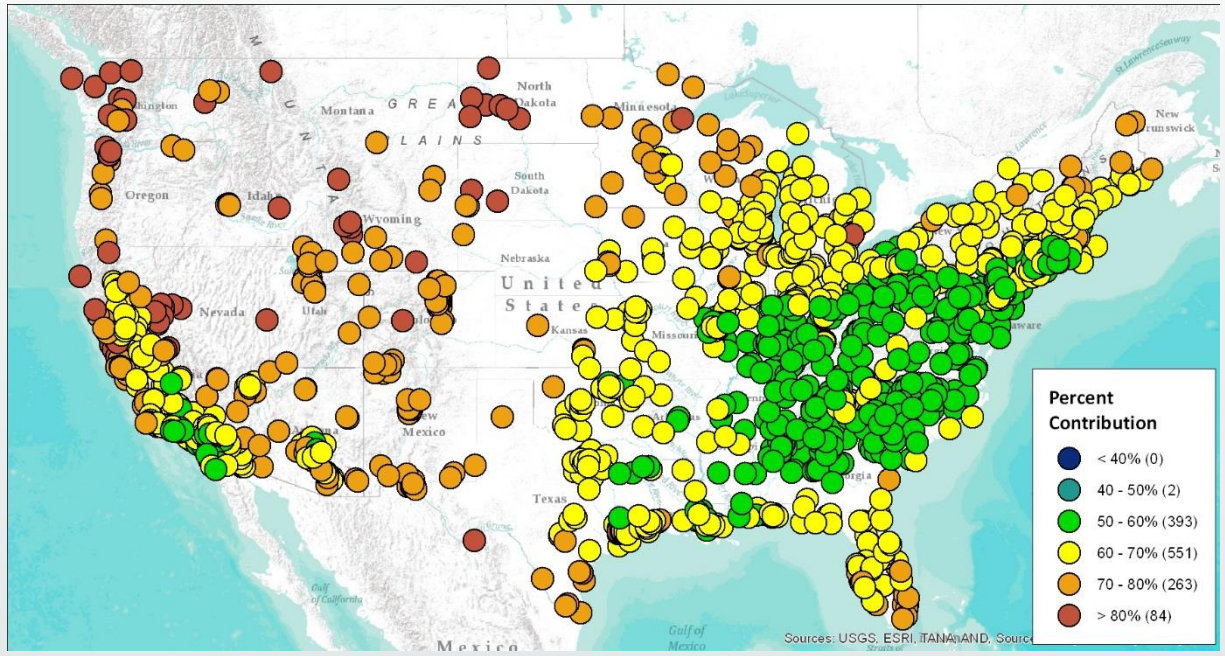

U.S. background



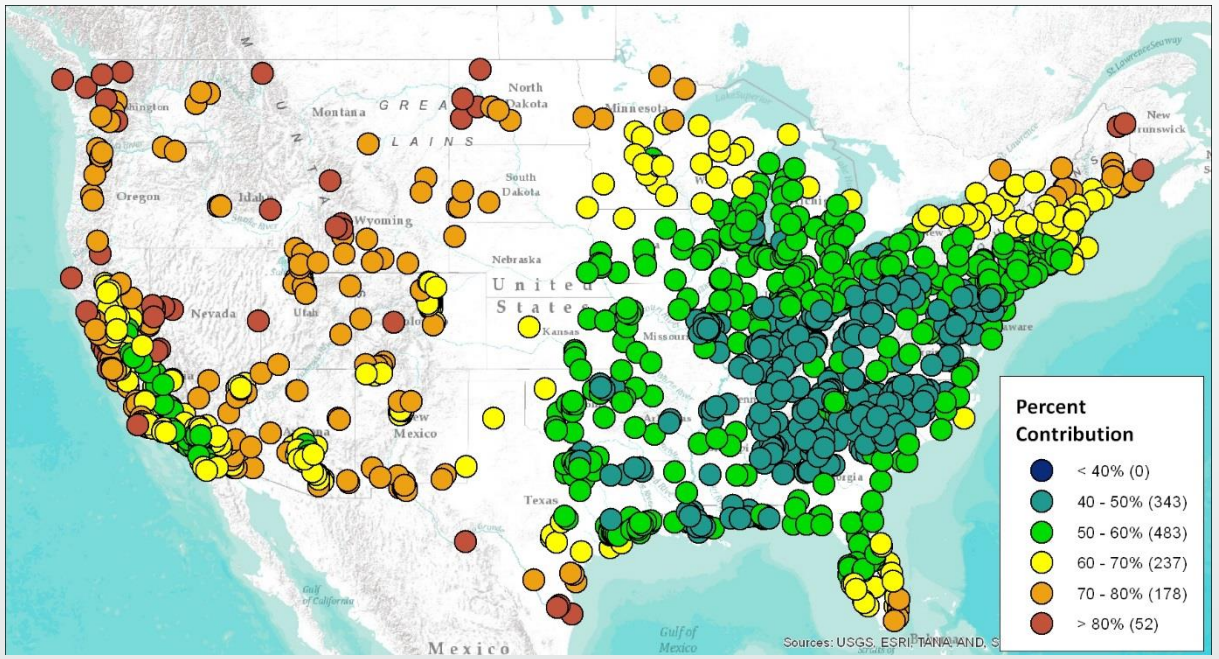

- Plots display Apr-Oct average NB and USB $O_3$ (MDA8) from zero out modeling by site
  - Natural background: 15-35 ppb across the U.S. with highest values in the inter-mountain WUS.
  - U.S. background: 25-50 ppb across the U.S. with highest values in the inter-mountain WUS.

# EPA estimates of mean fractional USB: Zero out vs. source apportionment (1 of 2)

Zero out

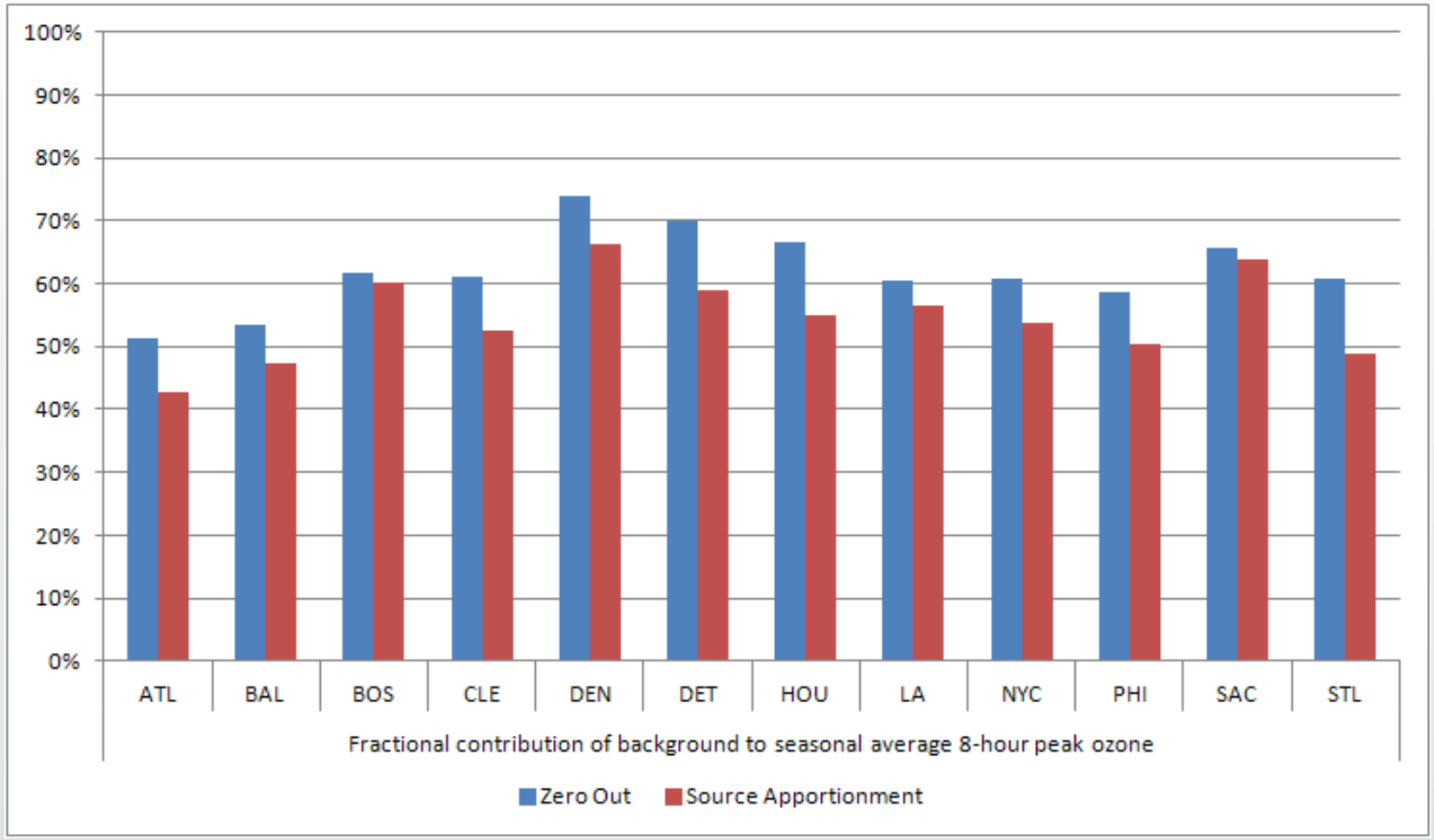



Source apportionment



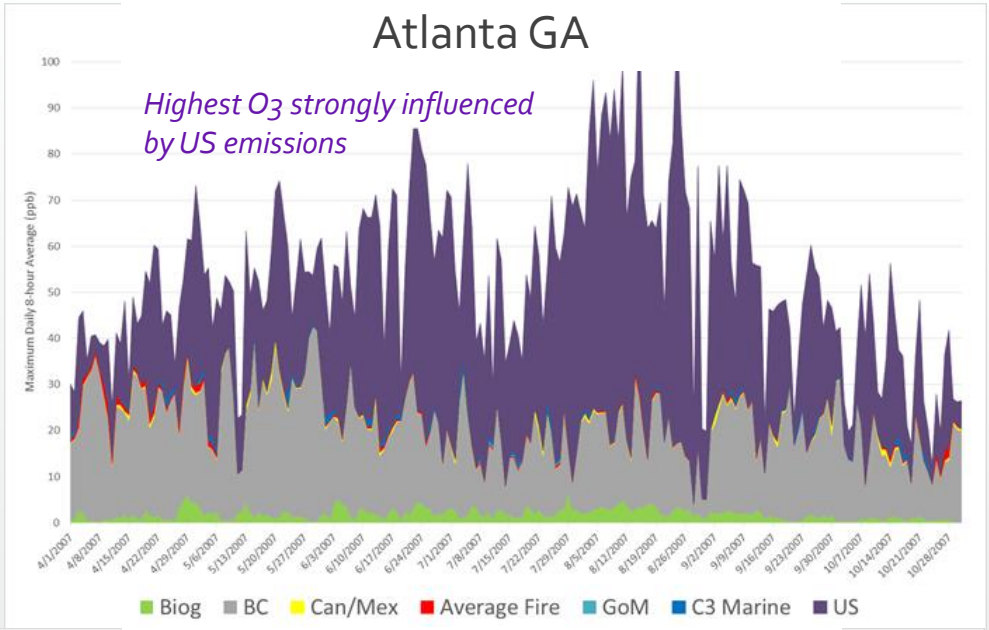

- Plots display Apr-Oct average fractional USB ozone (MDA8)
  - Source apportionment estimates of fractional USB ozone are generally slightly less than indicated by zero out
  - In some locations of the west, 70-90% of the mean ozone is comprised of USB. In the east, estimates are 40-60%.

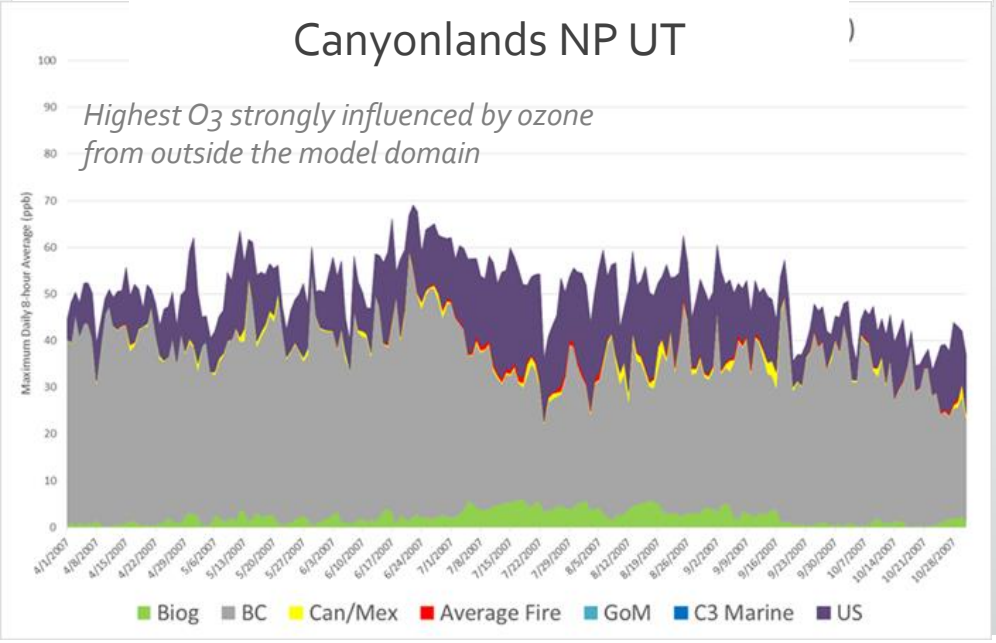
# EPA estimates of mean fractional USB: Zero out vs. source apportionment (2 of 2)




- The model estimates that 40-65% of the seasonal mean ozone is the result of USB
  - Denver is estimated to have the greatest contribution from U.S. background.
  - Atlanta is estimated to have the smallest contribution from background sources.

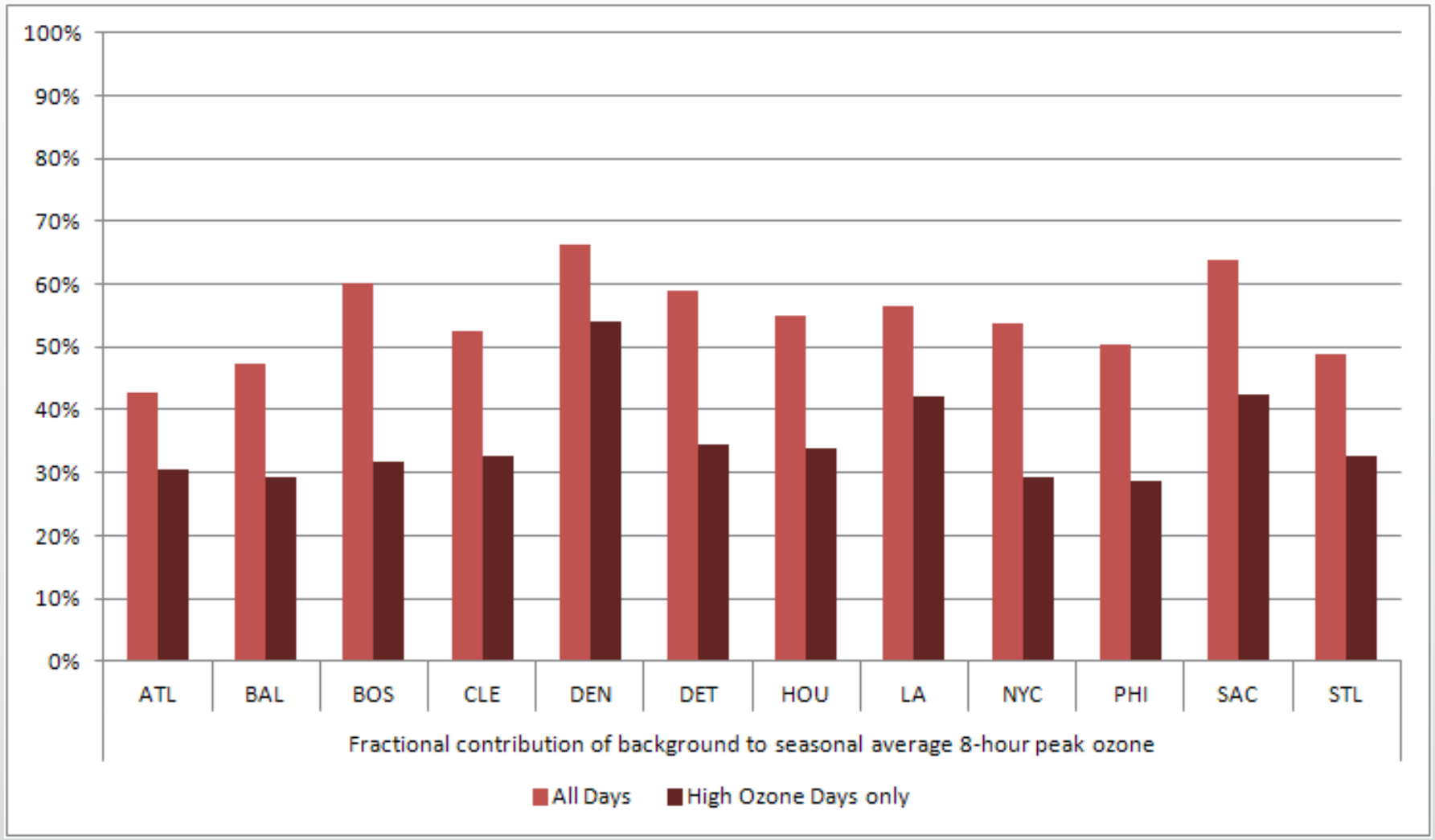
# EPA estimates of USB: Sample time series plots



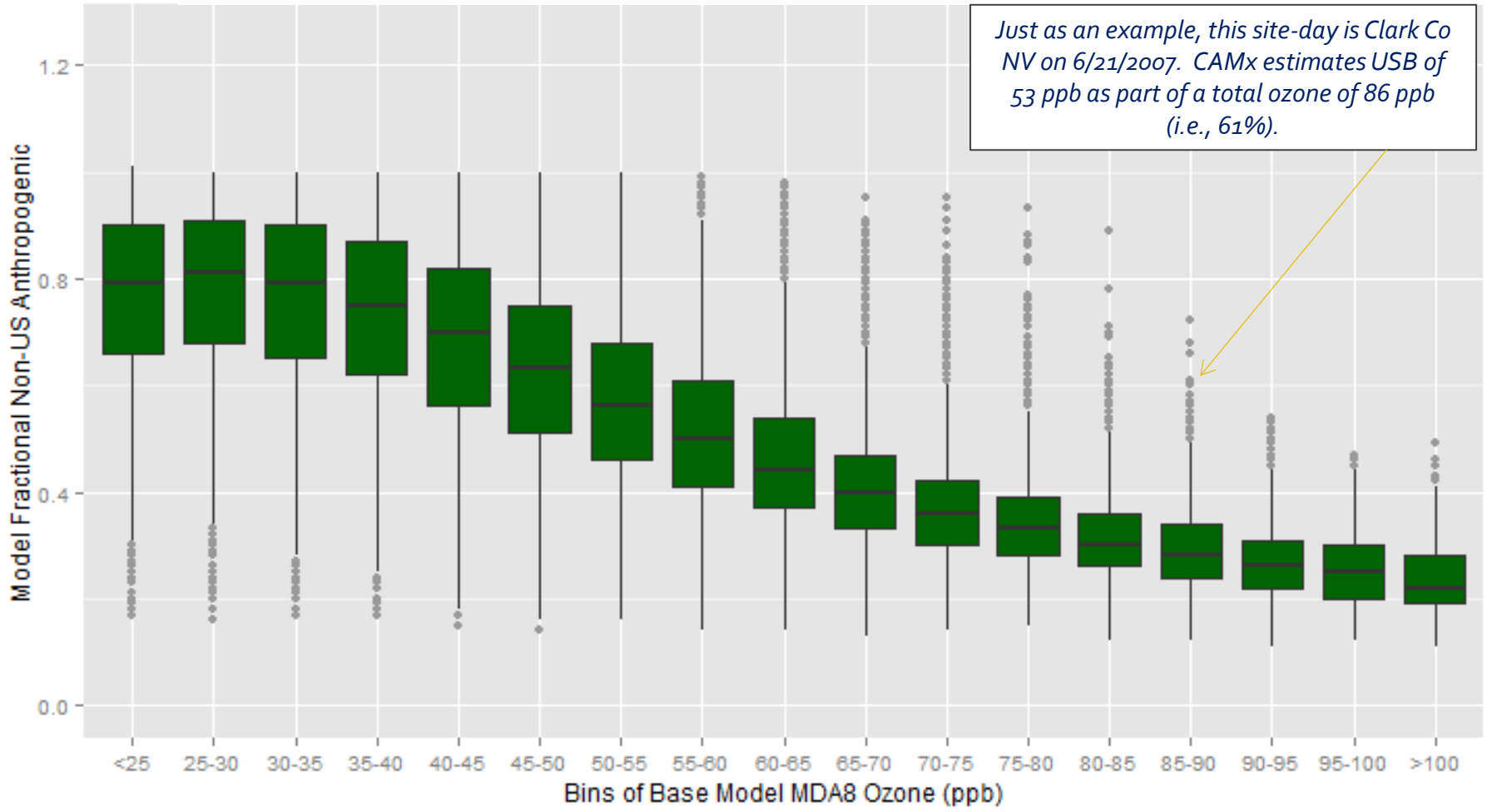

- Time series plots based on model source apportionment show varying contributions from different sources.
- Influence of boundary conditions is much larger over portions of the western States
  - Especially at higher-elevation sites in the late Spring / early Summer.
- Model suggests that boundary conditions, fires, and in-domain emissions from Canada and Mexico can influence ozone in the EUS (e.g., Atlanta), but highest contributions tend to be on low ozone days.

# EPA estimates of fractional USB: Seasonal means vs. high O3 days (1 of 2)




- On days in which the base modeled ozone is >= 70 ppb, USB comprises ~30-50% of the total ozone in these 12 urban areas
  - Denver is still estimated to have the greatest contribution from background (~50%) on high ozone days.
  - Several areas have contributions from background sources of ~30% on these days.

# EPA estimates of fractional USB: Seasonal means vs. high O3 days (2 of 2)

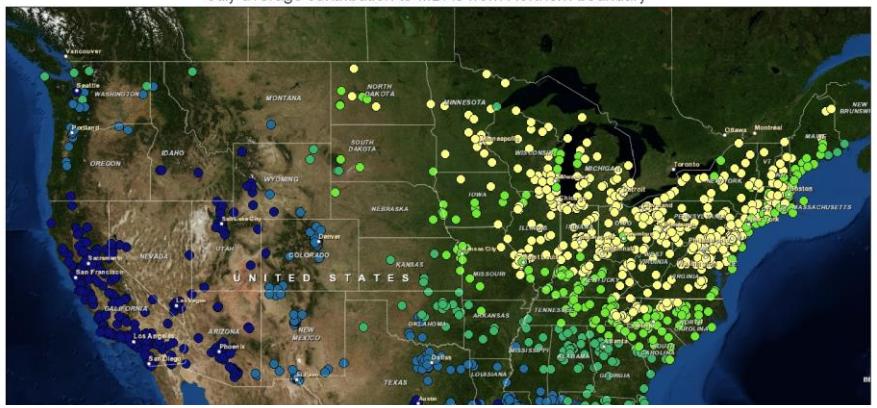



- The highest ozone events are generally less affected by background than lower ozone days.
- The large majority of exceedances are predominantly driven by U.S. emissions.
- High ozone events driven by BGO3 can occur but are typically associated w/ "events" (e.g., fires, intrusions, international plumes)

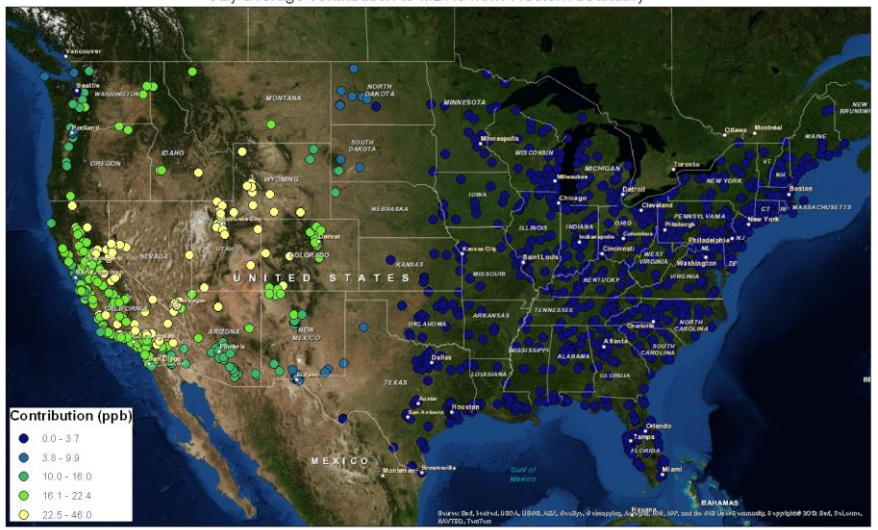
# EPA BGO3 estimates: Diagnostic analyses (1 of 2)

- Different locations in the U.S. are differentially affected by each lateral boundary
  - Sites in the western U.S. are largely impacts by the western boundary
  - Sites in the MARAMA region see most of their summer influence from the northern boundary

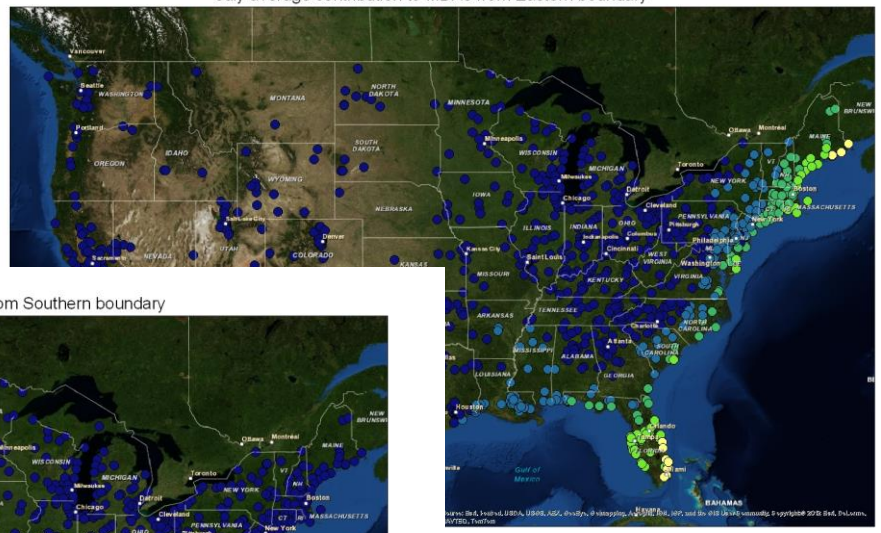
July average contribution to MDA8 from Northern boundary



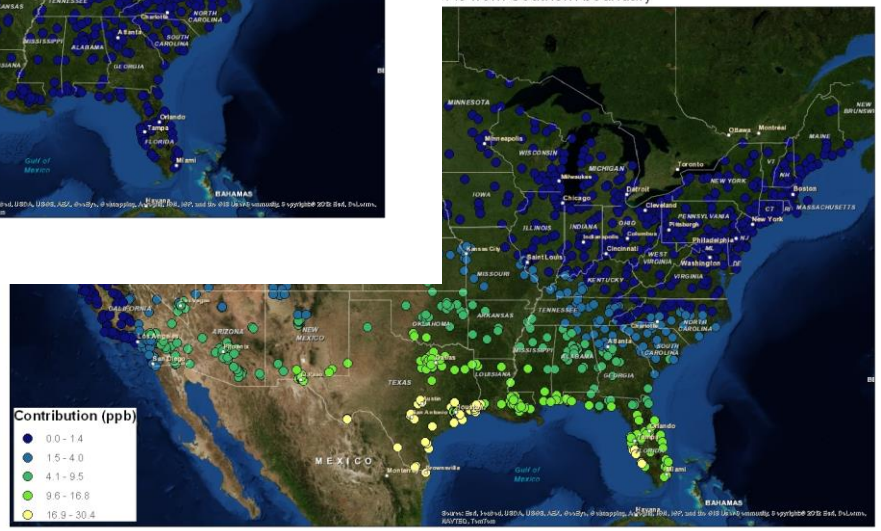

July average contribution to MDA8 from Western boundary




July average contribution to MDA8 from Eastern boundary



)A8 from Southern boundary



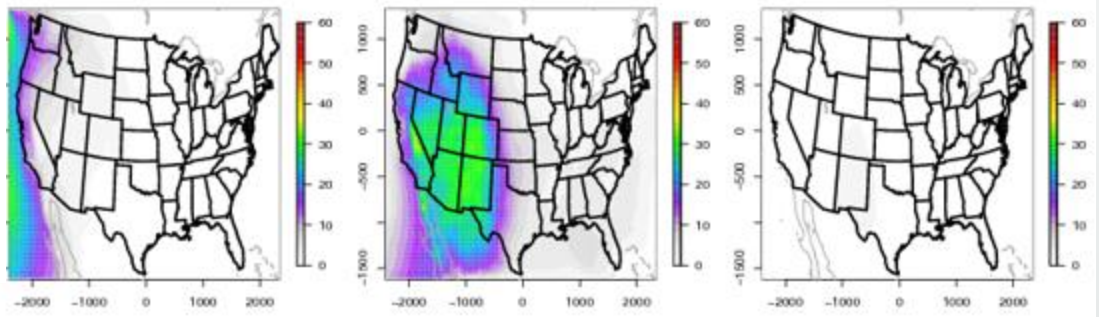
# EPA BGO3 estimates: Diagnostic analyses (2 of 2)

- Separate (2011) OSAT analysis indicates that upper tropospheric layers of the boundary are most relevant to U.S. impacts.
  - Especially in the spring and early summer
  - Results from forthcoming paper by K. Baker

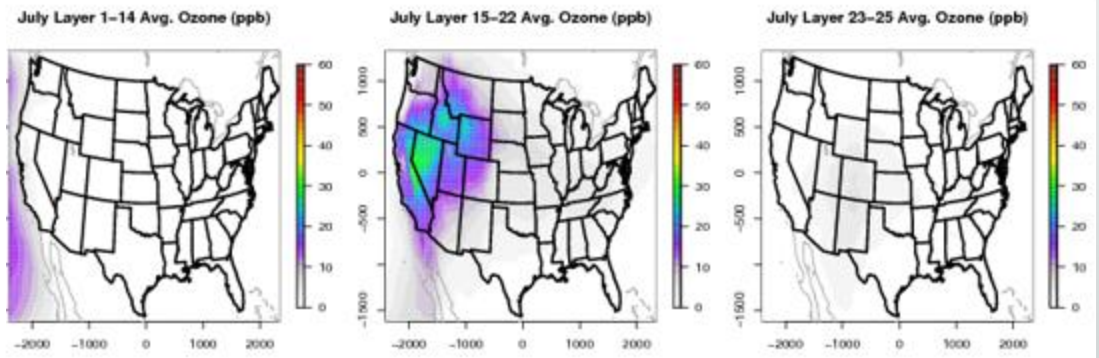
Western boundary

Layers 1-14 | Layers 15-22 | Layers 23-25

April

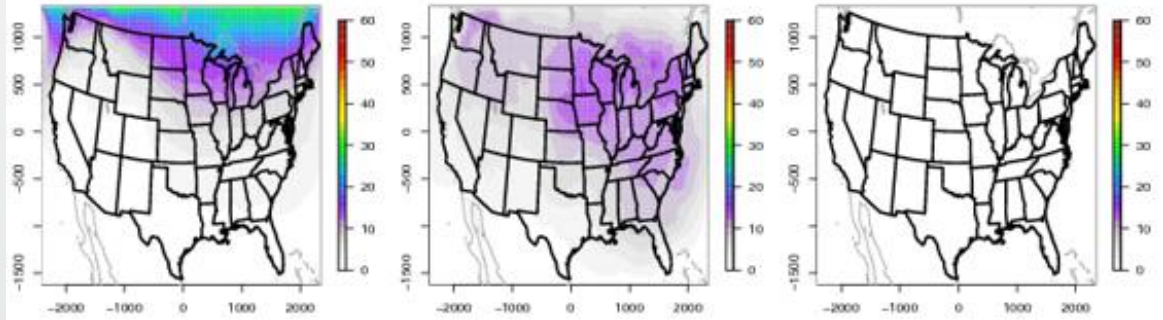


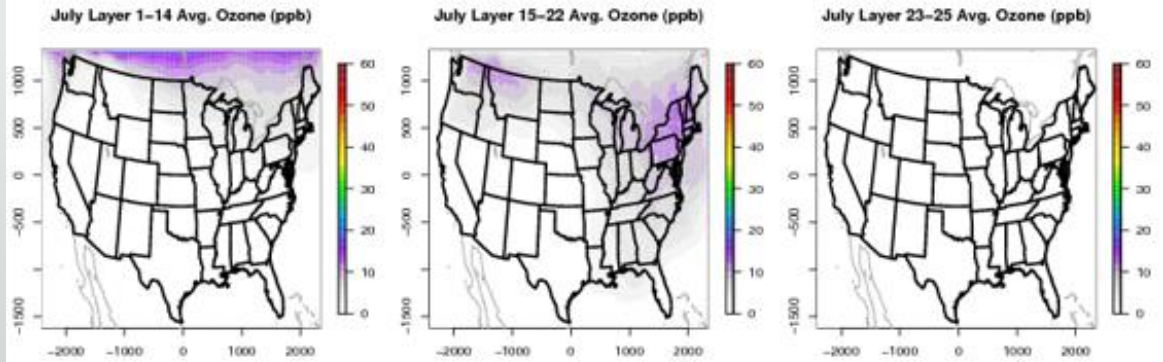
July




Northern boundary

Layers 1-14 | Layers 15-22 | Layers 23-25



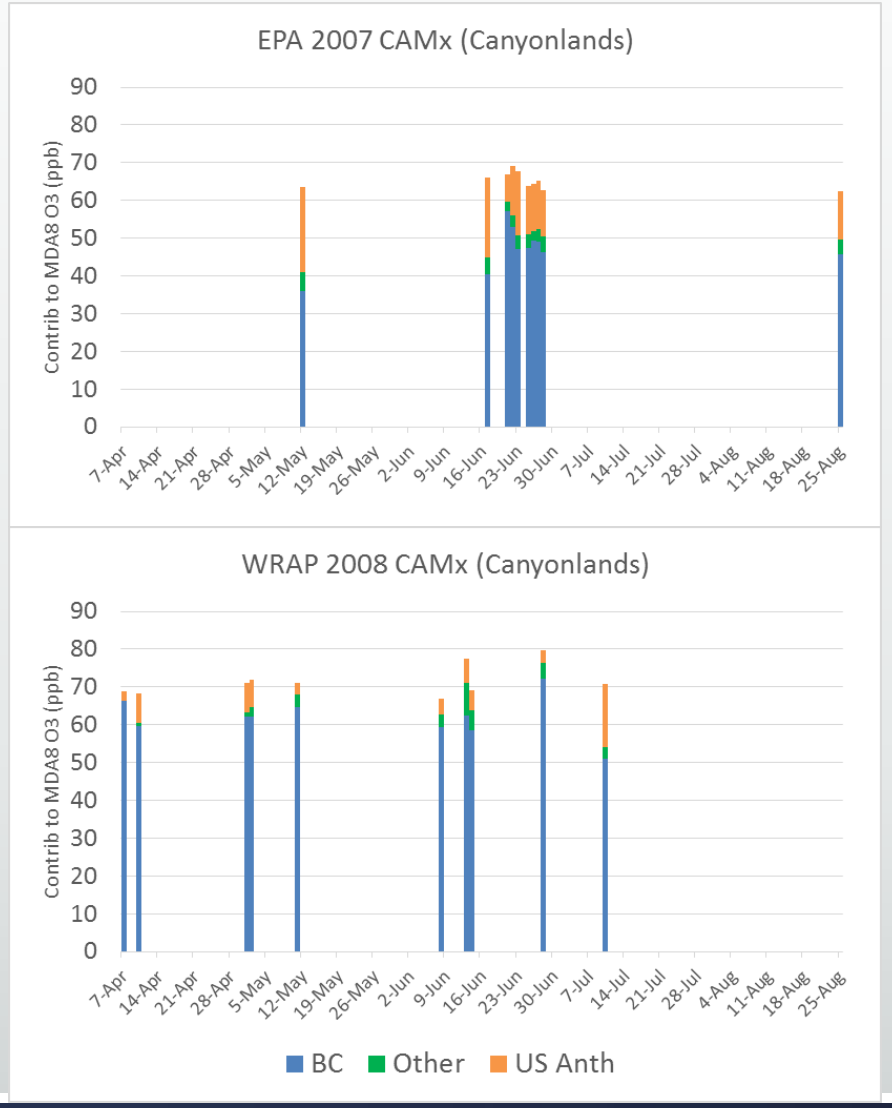


# Comparisons against other BGO3 modeling analyses (1 of 2)

- It is instructive to compare the 2007 CAMx OSAT/APCA estimates of background ozone influence to other similar modeling analyses:
  - Zhang et al., (2011): 2006 GEOS-Chem zero out
  - Emery et al., (2012): 2006 CAMx zero out
  - Lin et al., (2012): 2010 GFDL AM3 zero out and tracers
  - WRAP (2013): 2008 CAMx source apportionment
  - USEPA (2014): 2007 CMAQ zero out and CAMx source apportionment
  - Lefohn et al., (2014): 2006 CAMx source apportionment
  - USEPA (unpublished): 2011, 2017 CAMx source apportionment
- The various modeling analyses all confirm the general nature of background ozone:
  - Mean values of USB range from 25-50 ppb, but can be higher in discrete events
  - Highest values occur in the spring / early summer in intermountain WUS
  - However, the 2010 AM3 (Lin) and 2008 CAMx (WRAP) results tend to show higher BGO3 contributions than the other sets of modeling.

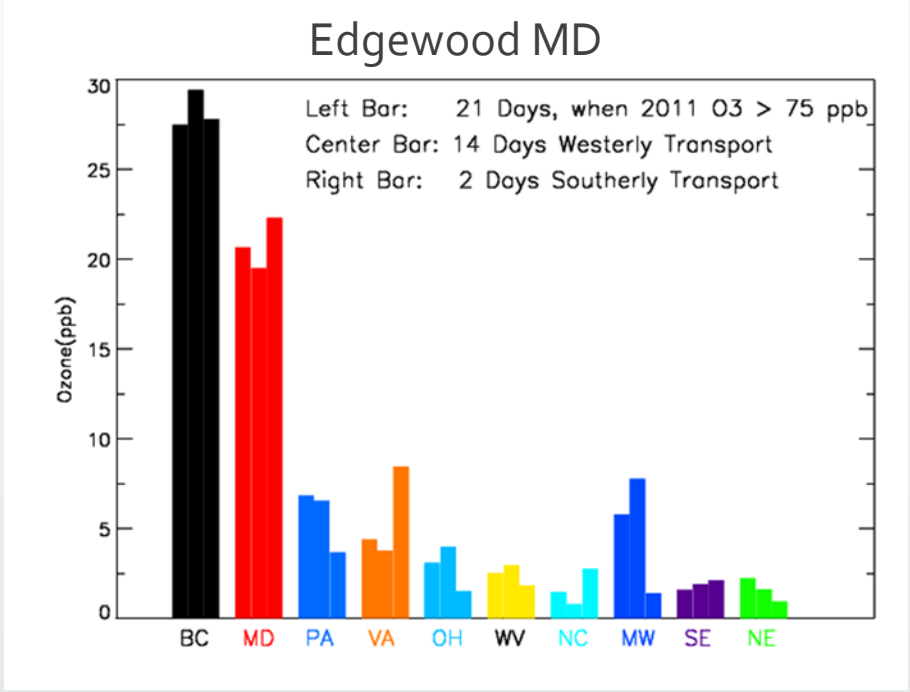
# Comparisons against other BGO3 modeling analyses (2 of 2)

- Background estimates can vary from model to model.
- Example on the right compares EPA 2007 OSAT estimates of boundary conditions at Canyonlands N.P. to same quantity in 2008 WRAP modeling.
  - EPA modeling suggests boundary contributions of 36-59 ppb on high days.
  - WRAP modeling suggest boundary contributions of 50-72 ppb on high days.
  - Causes of differences have been hard to pin down.
  - Need for continued evaluation and collaboration.



# EPA modeling plans to improve BGO3 estimates

- Looking for collaborations with the community at large
  - State partners, Federal partners, academic/stakeholder groups
- Need for additional data collection to enable thorough model performance evaluations
  - Targeted measurements in areas especially influenced by background
  - Additional routine non-surface measurements of ozone / precursors (e.g., lidar, satellite, sondes)
  - Continuous dynamic evaluations of models' ability to predict trends
- Better integration between the global and regional modeling communities
  - EPA expects to begin hemispheric CMAQ modeling in near-future
  - Work with HTAP to incorporate best available global runs into regional boundary conditions




*Draft preliminary results from D. Goldberg, pulled from Feb 2015 MDE presentation.*

# Potential opportunities for collaboration

- Formation of special issue workgroups
  - Stratospheric intrusion workgroup, WRAP-based forums, RPO calls, others?
- NASA Air Quality Applied Science Team (AQAST)
  - Partner atmospheric scientists with AQ managers to leverage earth science tools
  - Continually looking for new AQ issues for investigation
  - Led by Daniel Jacob (Harvard)
- CENRS Air Quality Research Subcommittee
  - Group devoted to improving information exchange between research and policy on air quality issues (e.g., background ozone)
  - Also tasked with enhancing the effectiveness and productivity of U.S. air quality research.
  - Currently chaired by John Daniel (NOAA ESRL)
- Others?

# Thanks. Questions?

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