**Supporting Information**

**for**

# Evaluating reduced-form modeling tools for simulating ozone and $PM_{2.5}$ monetized health impacts

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## Contents



## Detailed Methodology for Creating Air Quality Fields for Each Scenario

CMAQ and CAMx were applied with a domain covering the contiguous US with 12 km sized grid cells and representing the vertical atmosphere from the surface to 50 mb with 25 layers. The grid domain covered the contiguous US along with the southern portion of Canada and the Northern portion of Mexico. The models were applied with 2007 meteorology for the Tier 3 scenario, with 2011 meteorology for the CPPP scenario, the alternate 2023 projection methods scenario and the industrial sector scenarios and with 2016 meteorology for the scenario representing the projected change in EGU emissions from 2023 to 2026. Meteorological inputs were generated from annual applications of the Weather Research and Forecasting model [1]. CMAQ version 5.0.1 was applied for the Tier 3 scenario for 2007 and projected future year 2030 reference and control scenarios. CAMx version 6.10 and CMAQ version 5.2 were applied for 2011, future reference year 2025 and the 2025 control scenarios for CPPP and the cement kiln, refinery, and pulp & paper sector scenarios. CAMx version 7.1 was applied for 2016, future reference year 2023 and 2023 control scenarios for the alternate 2023 EGU projections method scenario and the 2023 to 2023 projected EGU changes scenario. Initial and lateral boundary chemical inflow were extracted from 2007 and 2011 GEOS-Chem global and 2016 hemispheric-CMAQ model simulations and translated to match the grid structure and chemical species used in CMAQ and CAMx [2]. Ozone and chemically speciated $PM_{2.5}$ output by the photochemical model were adjusted toward observation data to minimize situations where model agreement with ambient data is poor [3-6].

SABAQS was applied to generate summer season MDA8 ozone and annual average $PM_{2.5}$ surfaces for the projected 2025 future year reference scenario and the projected 2025 future year CPPP control. Two separate underlying source apportionment modeling simulations were used for this purpose. SABAQS was also applied to generate summer season MDA8 ozone and annual average $PM_{2.5}$ surfaces for the 2023 future year reference, the 2023 alternate EGU projection scenario and the 2023 to 2026 EGU changes scenario.

The first SABAQS application to the CPPP scenario applied inputs of source apportionment modeling available from the benefits assessment of the regulatory impacts assessment of EPA's 2020 affordable clean energy (ACE) rule [7]. The ACE rule modeling used a 2011 base year and projected emissions to a 2023 base year [8, 9] in an emissions case termed "2023en". Because the underlying meteorology and base-year national emissions inventory are all based on 2011 conditions for the 2023en source apportionment modeling as well as the full-form modeling of the CPPP, the 2023en source apportionment modeling is expected to match the full-form modeling fairly well. The 2023en source apportionment modeling tagged coal and non-coal EGU emissions separately by state. For the purpose of this paper, we aggregate the coal and non-coal EGU tags to create total state-level EGU emissions tags. Additionally, several states in the 2023en source apportionment were grouped together in the original source apportionment tags: ME/MA/NH/VT, ND/SD, OR/WA/ID, CT/RI. All other emissions source were also tagged but a scaling factor of 1 was used for all non-EGU.

To test the impacts of using a source apportionment modeling that was projected from a different base year, we also ran a source apportionment simulation for a 2026 future reference case termed "2026fj" that was projected from a 2016 base year (emissions and meteorology) [10]. Because the underlying meteorology and base-year national emissions inventory for the source apportionment case was different than the base year used for the full-form model, this case is not expected to match the full-form CPPP modeling as precisely. For the 2026fj source apportionment, total EGU emissions were tagged separately for each state. In several states there were none or very low emissions of EGU $SO_2$. Since the source apportionment contributions associated with EGU $SO_2$ emissions in those states were either missing or unreliable due to de minimus emissions, $S_{t,i}$ was set to 1 in those states, and the changes in $SO_2$ emissions from the CPPP reference and control cases were applied to neighboring states to maintain total national emissions changes equivalent to the full-form CPPP modeling case. For this purpose, emissions changes in NM were assigned to AZ, in VT were applied to NH, in MS were applied to LA, in OK were applied to TX, and in NV were applied to UT.

The 2023en source apportionment dataset and the 2026fj source apportionment dataset were applied to replicate the 2023 alternate EGU projection scenario and the 2023 to 2026 EGU changes scenario respectively.

Table S-1 provides a summary of all of the modeling simulations that were used to determine full-form CMAQ and CAMx air quality impacts as well as the modeling simulations that were used as inputs into the SABAQS reduced-form methodology.

Table S-1. Description of all modeling simulations used in this assessment.

| **Simulation** | **Type of model simulation** | **Meteorology and base year emissions** | **Future year emissions** | **Description** |
|---|---|---|---|---|
| 2030 base case | CMAQ | 2007 | 2030 | 2030 business as usual case |
| Tier 3 policy case | CMAQ | 2007 | 2030 | Tier 3 policy brute force scenario. Compare against 2030 base case for CMAQ Tier 3 policy impacts |
| 2025 base case | CMAQ and CAMx | 2011 | 2025 | 2025 business as usual case |
| CPPP policy case | CMAQ and CAMx | 2011 | 2025 | CPP proposal policy brute force scenario. Compare against 2025 base case for CPPP CMAQ and CAMx impacts |
| 2023 base case | CAMx | 2011 | 2023 | 2023 business as usual case projected off of 2011 |
| EGU sensitivity case A | CAMx | 2016 | 2023 | 2023 business as usual case projected off of 2016. Compare against 2023 base case for EGU sensitivity A CAMx impacts. |
| EGU sensitivity case B | CAMx | 2016 | 2026 | 2026 business as usual case projected off of 2016. Compare against Sensitivity case A for EGU sensitivity B CAMx impacts. |
| Pulp & paper sensitivity case | CMAQ | 2011 | 2025 | Pulp and paper sector brute force emissions sensitivity. Compare against 2025 base case for pulp & paper CMAQ impacts. |
| Cement kilns sensitivity case | CMAQ | 2011 | 2025 | Cement kiln sector brute force emissions sensitivity. Compare against 2025 base case for cement kiln CMAQ impacts. |
| Refineries sensitivity | CMAQ | 2011 | 2025 | Refineries sector brute force emissions sensitivity. Compare against 2025 base case for refineries CMAQ impacts. |
| 2023en source apportionment case | CAMx source apportionment | 2011 | 2023 | 2023 business as usual case projected from 2011. Source apportionment tracking served as inputs into SABAQS method. |
| 2026fj source apportionment case | CAMx source apportionment | 2016 | 2026 | 2026 business as usual case projected from 2016. Source apportionment tracking served as inputs into SABAQS method |

# Additional Maps Comparing CAMx and SABAQS Air Quality Surfaces

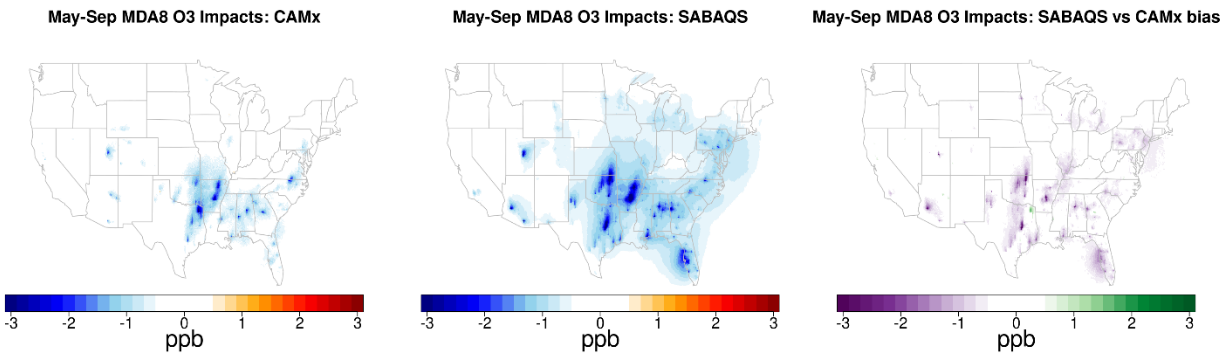


Figure S1. Comparison of CAMx and 2026fj-based SABAQS estimates of CPPP impacts on May-Sep MDA8 ozone. CAMx estimates shown on the left, SABAQS estimates shown in the middle and the difference between the two surfaces shown on the right with purple colors indicating a larger impact from SABAQS and green colors indicating a larger impact from CAMx.

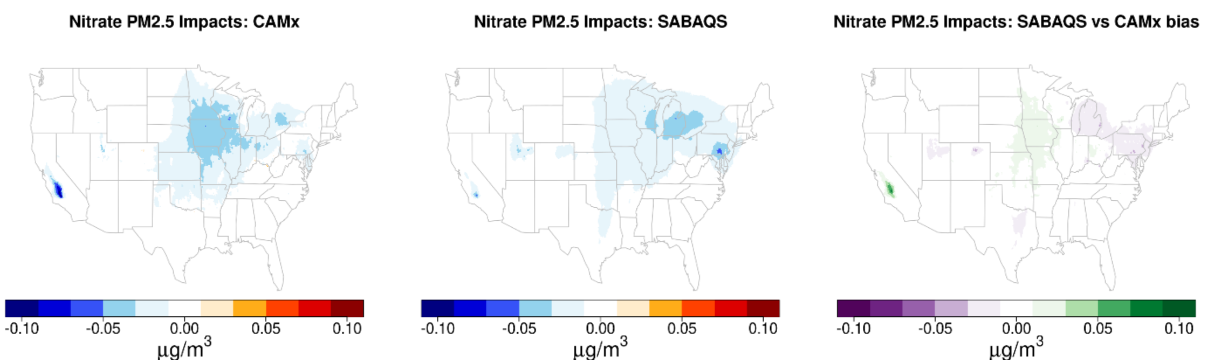


Figure S2. Comparison of CAMx and 2026fj-based SABAQS estimates of CPPP impacts on annual average $PM_{2.5}$ nitrate. CAMx estimates shown on the left, SABAQS estimates shown in the middle and the difference between the two surfaces shown on the right with purple colors indicating a larger impact from SABAQS and green colors indicating a larger impact from CAMx.

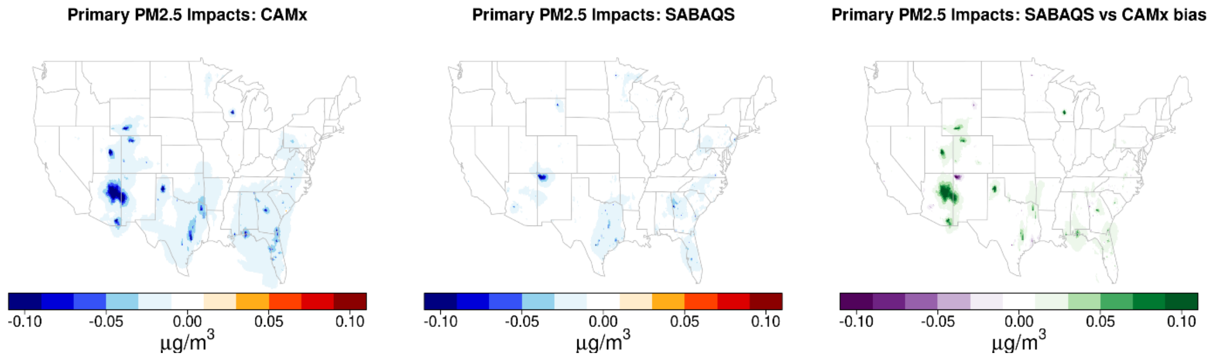


Figure S3. Comparison of CAMx and 2026fj-based SABAQS estimates of CPPP impacts on annual average primary $PM_{2.5}$ (EC and crustal material). CAMx estimates shown on the left, SABAQS estimates shown in the middle and the difference between the two surfaces shown on the right with purple colors indicating a larger impact from SABAQS and green colors indicating a larger impact from CAMx.

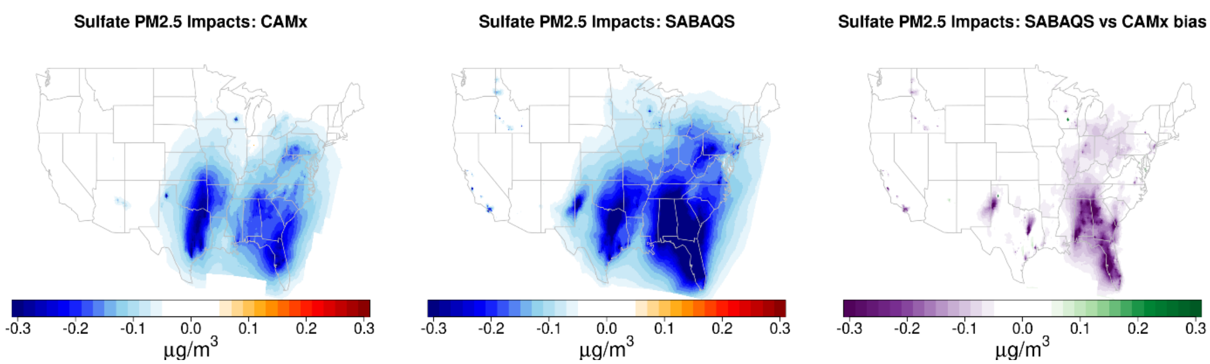


Figure S4. Comparison of CAMx and 2026fj-based SABAQS estimates of CPPP impacts on annual average $PM_{2.5}$ sulfate. CAMx estimates shown on the left, SABAQS estimates shown in the middle and the difference between the two surfaces shown on the right with purple colors indicating a larger impact from SABAQS and green colors indicating a larger impact from CAMx.

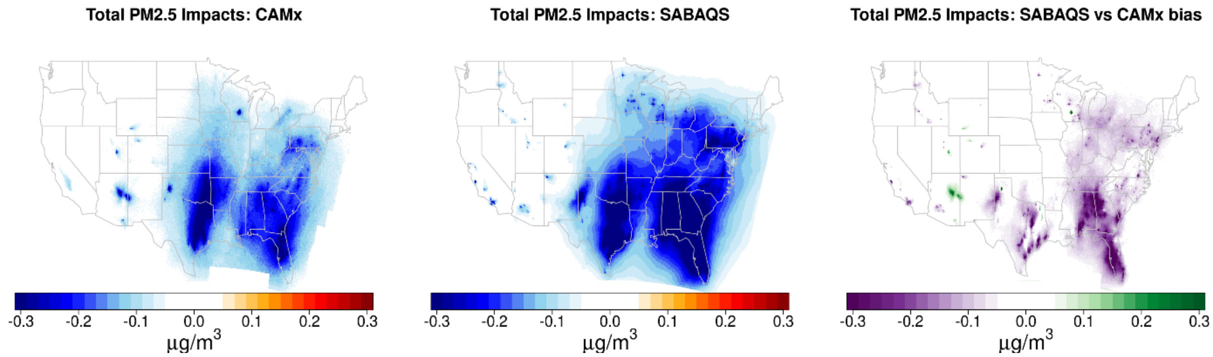


Figure S5. Comparison of CAMx and 2026fj-based SABAQS estimates of CPPP impacts on annual average total $PM_{2.5}$ (nitrate plus primary $PM_{2.5}$ plus sulfate). CAMx estimates shown on the left, SABAQS estimates shown in the middle and the difference between the two surfaces shown on the right with purple colors indicating a larger impact from SABAQS and green colors indicating a larger impact from CAMx.

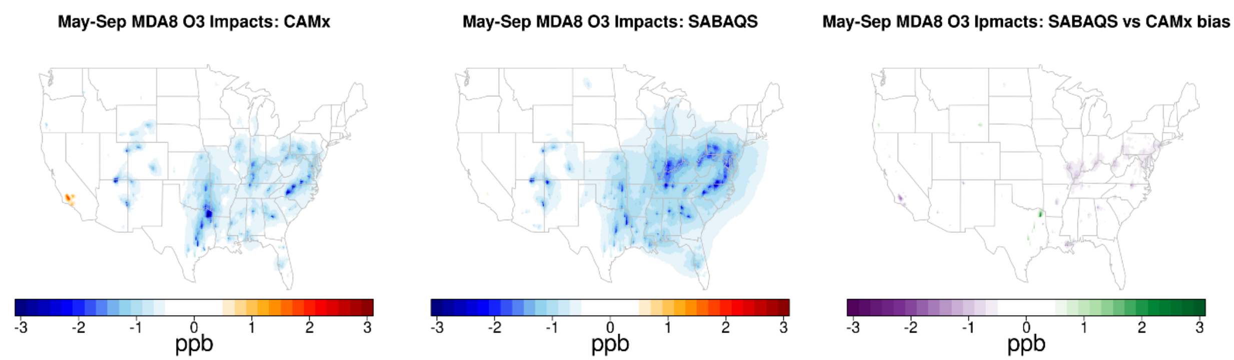


Figure S6. Comparison of CAMx and SABAQS estimates of EGU Sensitivity A impacts on May-Sep MDA8 ozone. CAMx estimates shown on the left, SABAQS estimates shown in the middle and the difference between the two surfaces shown on the right with purple colors indicating a larger negative impact or a smaller positive impact from SABAQS and green colors indicating a larger negative impact or a smaller positive impact from CAMx.

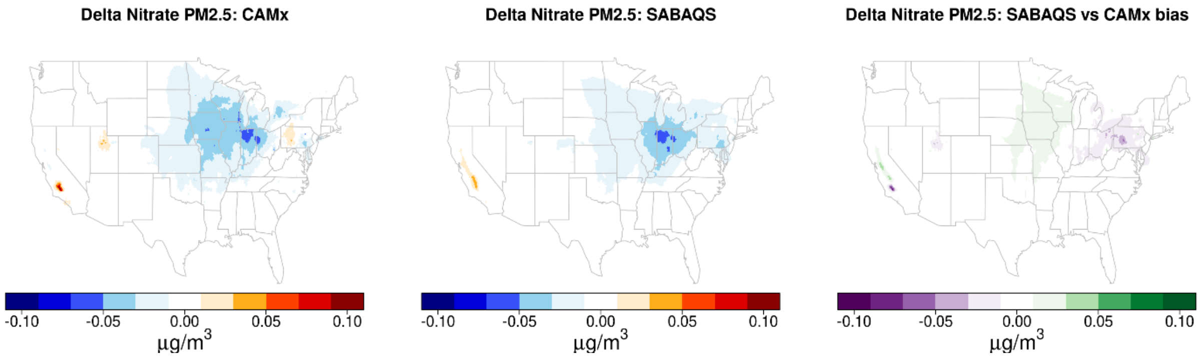


Figure S7. Comparison of CAMx and SABAQS estimates of EGU Sensitivity A impacts on annual average $PM_{2.5}$ nitrate. CAMx estimates shown on the left, SABAQS estimates shown in the middle and the difference between the two surfaces shown on the right with purple colors indicating a larger negative impact or a smaller positive impact from SABAQS and green colors indicating a larger negative impact or a smaller positive impact from CAMx.

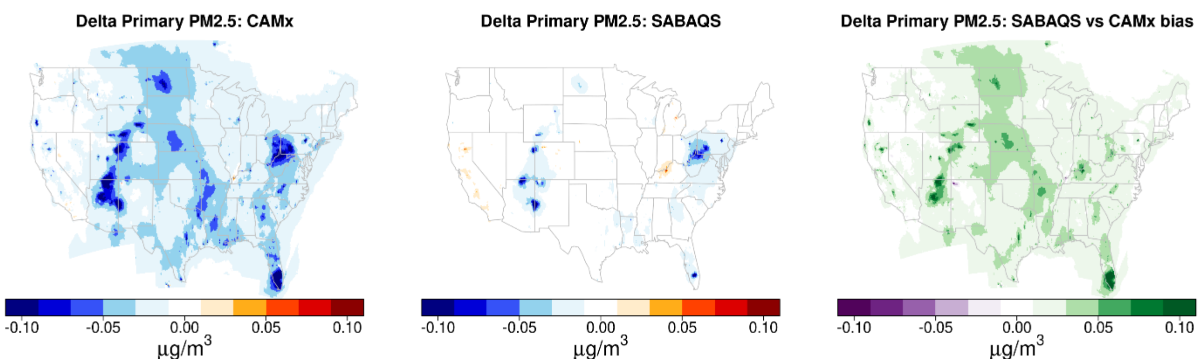


Figure S8. Comparison of CAMx and SABAQS estimates of EGU Sensitivity A impacts on annual average primary $PM_{2.5}$ (EC and crustal material). CAMx estimates shown on the left, SABAQS estimates shown in the middle and the difference between the two surfaces shown on the right with purple colors indicating a larger negative impact or a smaller positive impact from SABAQS and green colors indicating a larger negative impact or a smaller positive impact from CAMx.

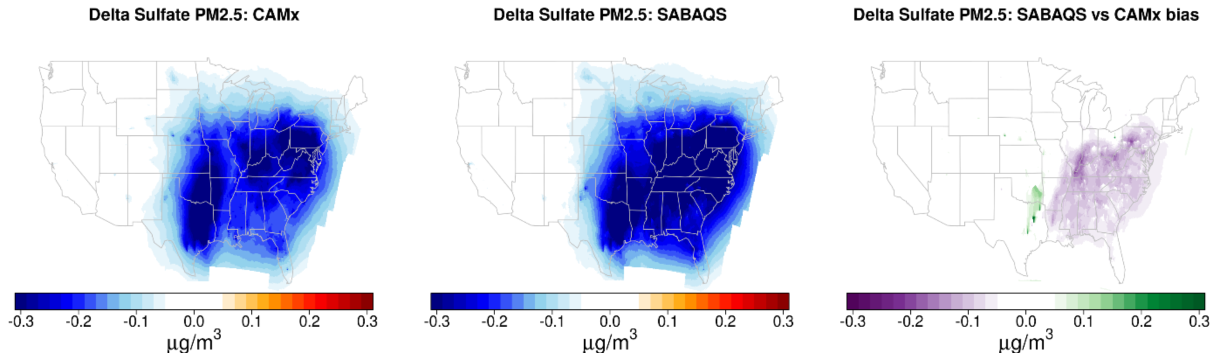


Figure S9. Comparison of CAMx and SABAQS estimates of EGU Sensitivity A impacts on annual average $PM_{2.5}$ sulfate. CAMx estimates shown on the left, SABAQS estimates shown in the middle and the difference between the two surfaces shown on the right with purple colors indicating a larger impact from SABAQS and green colors indicating a larger impact from CAMx.

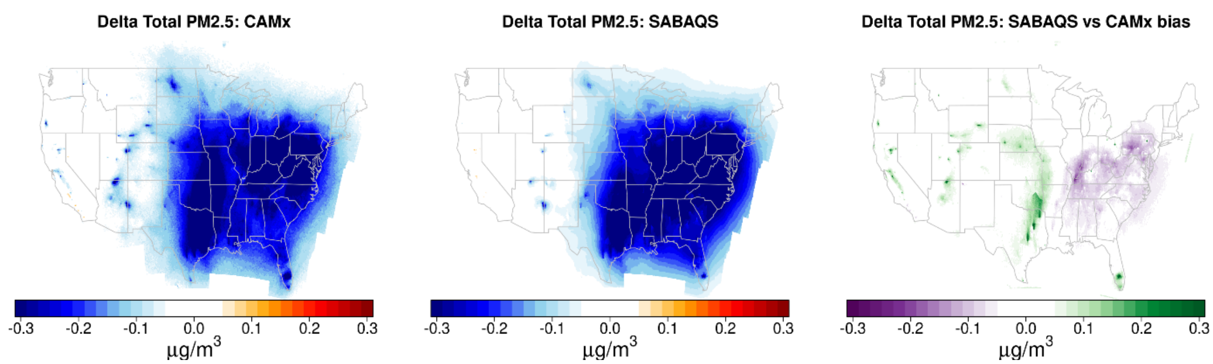


Figure S10. Comparison of CAMx and SABAQS estimates of EGU Sensitivity A impacts on annual average total $PM_{2.5}$ (nitrate plus primary $PM_{2.5}$ plus sulfate). CAMx estimates shown on the left, SABAQS estimates shown in the middle and the difference between the two surfaces shown on the right with purple colors indicating a larger impact from SABAQS and green colors indicating a larger impact from CAMx.

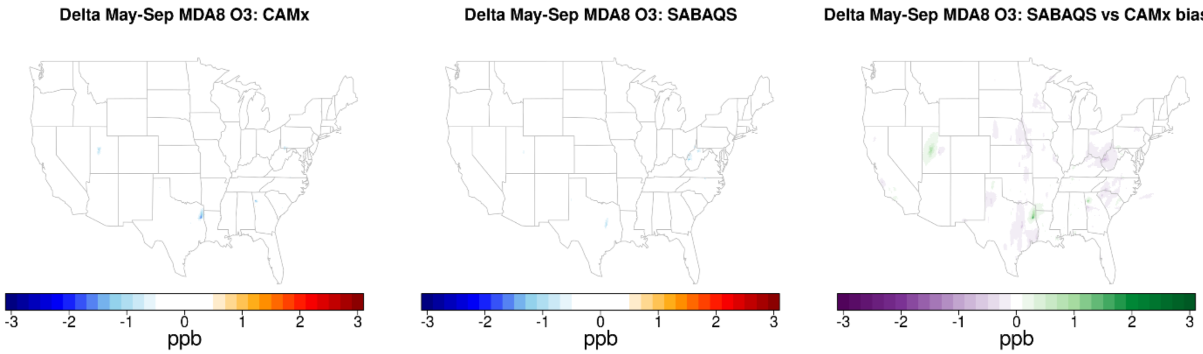


Figure S11. Comparison of CAMx and SABAQS estimates of EGU Sensitivity B impacts on May-Sep MDA8 ozone. CAMx estimates shown on the left, SABAQS estimates shown in the middle and the difference between the two surfaces shown on the right with purple colors indicating a larger impact from SABAQS and green colors indicating a larger impact from CAMx.

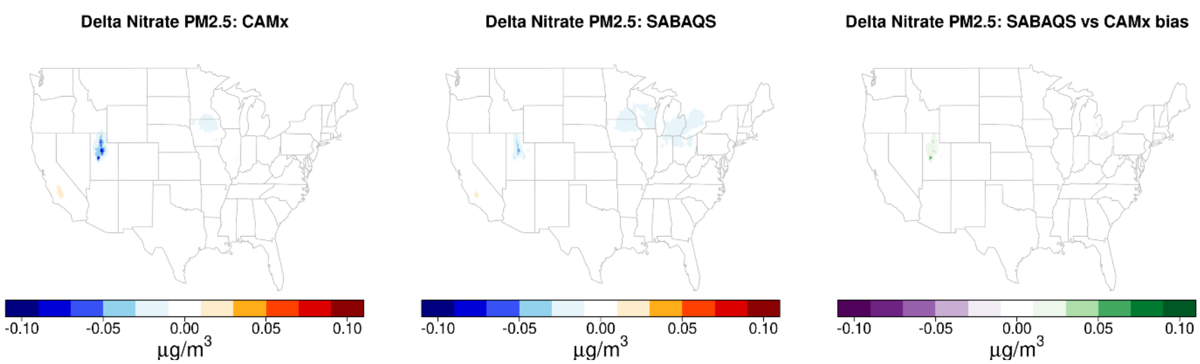


Figure S12. Comparison of CAMx and SABAQS estimates of EGU Sensitivity B impacts on annual average $PM_{2.5}$ nitrate. CAMx estimates shown on the left, SABAQS estimates shown in the middle and the difference between the two surfaces shown on the right with purple colors indicating a larger negative impact or a smaller positive impact from SABAQS and green colors indicating a larger negative impact or a smaller positive impact from CAMx.

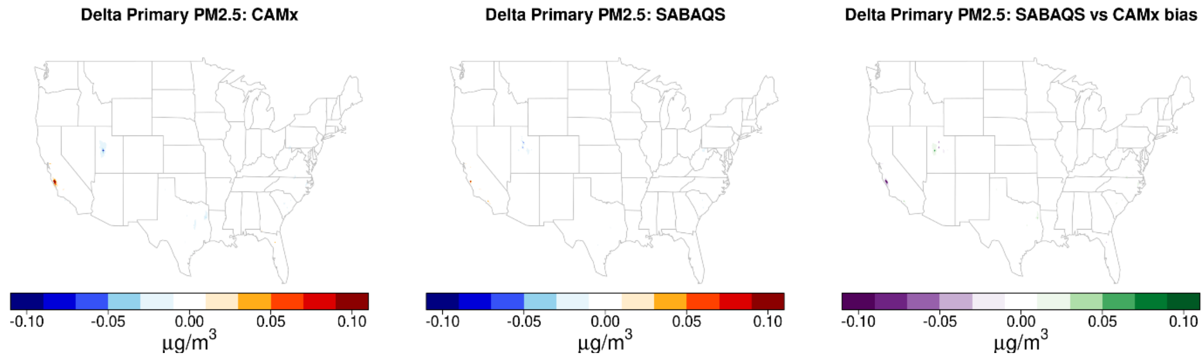


Figure S13. Comparison of CAMx and SABAQS estimates of EGU Sensitivity B impacts on annual average primary $PM_{2.5}$ (EC and crustal material). CAMx estimates shown on the left, SABAQS estimates shown in the middle and the difference between the two surfaces shown on the right with purple colors indicating a larger negative impact or a smaller positive impact from SABAQS and green colors indicating a larger negative impact or a smaller positive impact from CAMx.

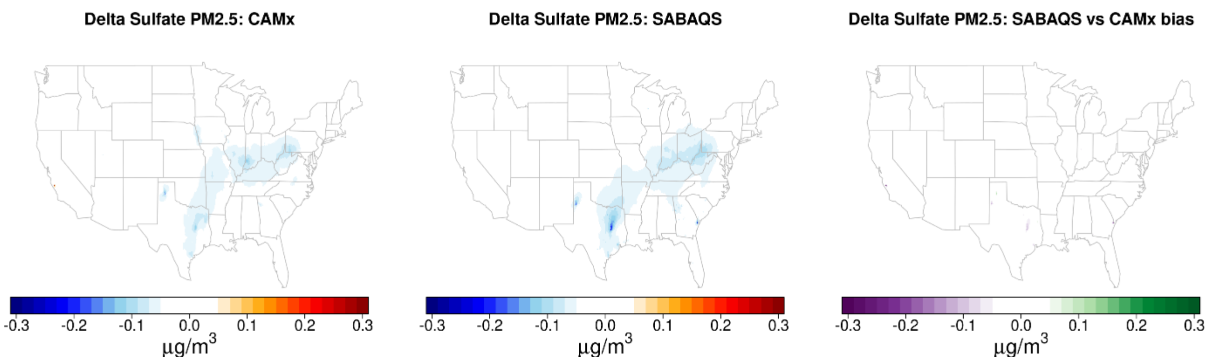


Figure S14. Comparison of CAMx and SABAQS estimates of EGU Sensitivity B impacts on annual average $PM_{2.5}$ sulfate. CAMx estimates shown on the left, SABAQS estimates shown in the middle and the difference between the two surfaces shown on the right with purple colors indicating a larger impact from SABAQS and green colors indicating a larger impact from CAMx.

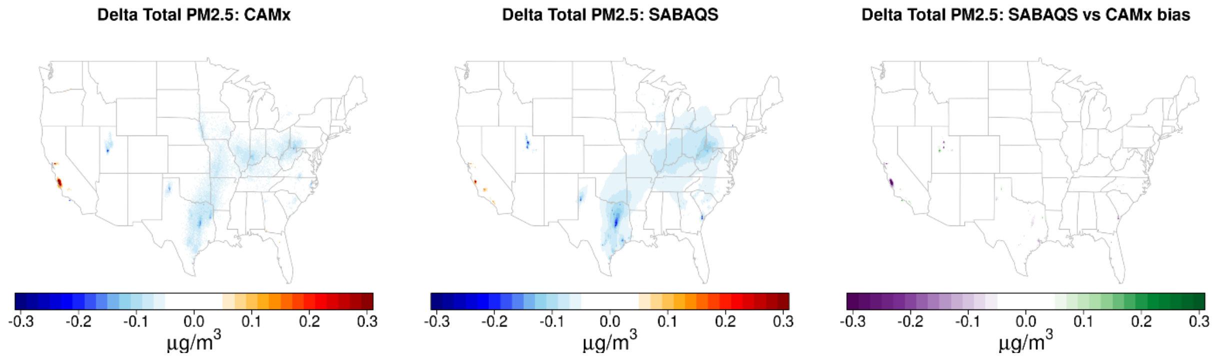


Figure S15. Comparison of CAMx and SABAQS estimates of EGU Sensitivity B impacts on annual average total $PM_{2.5}$ (nitrate plus primary $PM_{2.5}$ plus sulfate). CAMx estimates shown on the left, SABAQS estimates shown in the middle and the difference between the two surfaces shown on the right with purple colors indicating a larger negative impact or a smaller positive impact from SABAQS and green colors indicating a larger negative impact or a smaller positive impact from CAMx.

## Additional Benefits Results Tables

Table S-2: Monetized $PM_{2.5}$ health impacts (2019$ billion) for each emissions scenario. Impacts are provided for speciated components of $PM_{2.5}$ (nitrate from $NO_X$, sulfate from $SO_2$, and primary $PM_{2.5}$) and the sum of speciated components (total $PM_{2.5}$). Benefits derived from full-form modeling simulations are shown in bold.

| Scenario | MODEL | NOX | SO2 | Primary PM2.5 | Total PM2.5 |
|---|---|---|---|---|---|
| **CPPP** | **CMAQ/BenMAP** | **1.7** | **15.4** | **5.7** | **22.8** |
| | **CAMx/BenMAP** | **1.4** | **15.6** | **2.3** | **19.3** |
| | InMAP | 4.2 | 11.3 | 3.0 | 18.6 |
| | AP2 | 2.3 | 9.6 | 2.7 | 14.9 |
| | EASIUR | 3.0 | 9.5 | 5.5 | 18.3 |
| | SA BPT[a] | 2.7 | 31.2 | 8.6 | 42.5 |
| | SABAQS/BenMAP[b] | 1.7 | 27.5 | 3.7 | 32.9 |
| **EGU Sensitivity A** | **CAMx/BenMAP** | **1.7** | **32.3** | **4.2** | **41.0** |
| | InMAP | 4.5 | 21.4 | 2.0 | 27.5 |
| | AP2 | 2.4 | 18.2 | 2.4 | 22.7 |
| | EASIUR | 3.4 | 18.7 | 3.8 | 25.5 |
| | SA BPT[a] | 2.9 | 51.2 | 5.6 | 59.7 |
| | SABAQS/BenMAP | 1.8 | 39.5 | 1.2 | 43.3 |
| **EGU Sensitivity B** | **CAMx/BenMAP** | **0.3** | **5.0** | **0.2** | **5.2** |
| | InMAP | 0.8 | 2.9 | 0.2 | 3.9 |
| | AP2 | 0.5 | 2.4 | 0.2 | 3.0 |
| | EASIUR | 0.5 | 2.7 | 0.5 | 3.7 |
| | SA BPT[a] | 0.5 | 7.8 | 0.8 | 9.1 |
| | SABAQS/BenMAP | 0.5 | 5.9 | 0.1 | 6.7 |

| | | | | | |
|---|---|---|---|---|---|
| **Tier 3** | **CMAQ/BenMAP** | **1.9** | **0.3** | **4.2** | **6.4** |
| | InMAP | 6.2 | 0.4 | 1.8 | 10.8 |
| | AP2 | 3.2 | 0.6 | 1.1 | 7.4 |
| | EASIUR | 4.3 | 0.4 | 1.7 | 6.4 |
| | SA BPT[c] | 2.5 | 1.7 | 5.9 | 10.1 |
| | SA BPT[d] | 1.9 | 1.1 | 3.2 | 6.2 |
| **Cement** | **CMAQ/BenMAP** | **0.6** | **2.7** | **1.3** | **4.6** |
| | InMAP | 1.1 | 1.7 | 2.0 | 4.8 |
| | AP2 | 0.6 | 1.7 | 1.3 | 3.6 |
| | EASIUR | 0.9 | 1.5 | 2.1 | 4.5 |
| | SA BPT[a] | 1.4 | 2.3 | 2.0 | 5.7 |
| **Refinery** | **CMAQ/BenMAP** | **0.2** | **0.8** | **0.5** | **1.5** |
| | InMAP | 0.5 | 0.5 | 0.6 | 1.6 |
| | AP2 | 0.2 | 0.5 | 0.5 | 1.2 |
| | EASIUR | 0.4 | 0.4 | 0.6 | 1.4 |
| | SA BPT[a] | 0.8 | 0.8 | 1.4 | 3.0 |
| **Pulp & Paper** | **CMAQ/BenMAP** | **0.1** | **1.6** | **0.5** | **2.3** |
| | InMAP | 0.3 | 0.9 | 0.4 | 1.6 |
| | AP2 | 0.1 | 0.9 | 0.3 | 1.3 |
| | EASIUR | 0.2 | 1.0 | 0.7 | 1.9 |
| | SA BPT[a] | 0.4 | 1.4 | 1.0 | 2.8 |

[a] Table 8 US EPA (2023) [11]

[b] SABAQS results based on the CPPP: 2023en

[c] Wolfe et al. (2019)[12] Table 2 highest national BPT for Light duty class

[d] Wolfe et al. (2019) [12] Table 2 smallest eastern US BPT for Light duty class

Table S-3: Monetized ozone health impacts (2019$billion) for each emissions scenario. Benefits derived from full-form modeling simulations are shown in bold.

| Scenario | MODEL | Monetized health impacts |
|---|---|---|
| **CPPP** | **CAMx/BenMAP** | **9.1** |
| | SABAQS/BenMAP[a] | 18.3 |
| | SA BPT | 24.0 |
| **EGU Sensitivity A** | **CAMx/BenMAP** | **11.4** |
| | SABAQS/BenMAP[a] | 18.2 |
| | SA BPT | 19.9 |
| **EGU Sensitivity B** | **CAMx/BenMAP** | **1.2** |
| | SABAQS/BenMAP[a] | 1.9 |
| | SA BPT | 2.7 |
| **Cement** | **CMAQ/BenMAP** | **3.3** |
| | SA BPT | 3.6 |
| **Refinery** | **CMAQ/BenMAP** | **0.6** |
| | SA BPT | 1.4 |
| **Pulp & Paper** | **CMAQ/BenMAP** | **1.1** |
| | SA BPT | 1.1 |

[a] SABAQS results based on the CPPP: 2023en

[b] $NO_x$ values from Table 8 US EPA (2023) [11]

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