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Development of the Expedited Modeling of Burn Events Results (EMBER) Datasets for 2021, 2022, 2024, and 2025

U.S. Environmental Protection Agency
Office of State Air Partnerships
Air Quality Assessment Division

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1. Background Information

The U.S. Environmental Protection Agency (EPA) has developed the Expedited Modeling of Burn Events Results (EMBER). EMBER is a screening-level modeling dataset for fire impacts on ozone concentrations in the U.S. The EPA first released EMBER data for the 2023 wildfire season in December 2024 and documented the methodology and results in a journal article[1]. This technical support document (TSD) represents an updated data set and describes four additional years of EMBER modeling that are being released by the EPA: 2021, 2022, 2024. The purpose of this document is to describe the methods and inputs used for developing the 2021, 2022, 2024 and 2025 EMBER datasets.

2. Model inputs and configuration

2.1 Model Simulations

The 2021, 2022, 2024, and 2025 EMBER model simulations were performed using the most recent public release of the Community Multiscale Air Quality (CMAQ) model version 5.5[2]. This is an update from the 2023 modeling that used the previous CMAQv5.4 model version. For each year, three CMAQ simulations were run: a base model simulation and two zero-out emissions scenarios[3]. The base year simulation provides model estimates of air pollution concentrations across the U.S. for the modeled year. A "zero fires" and a "zero fires in Canada and Mexico" simulation were also performed for each model year. These two simulations estimate air pollution levels in the U.S. that would have occurred if there had been no prescribed fires or wildfires (together referred to as wildland fires) in the U.S., Canada, or Mexico (zero fires) or if there had been no wildland fires in Canada and Mexico only (zero Canada and Mexico[4] fires). The impact of fires on ozone concentrations was calculated as the difference between the base simulation ozone concentration and the zero fires simulation ozone concentration. Similarly, the impacts of fires from Canada and Mexico alone were calculated as the difference between the base simulation and the zero Canada and Mexico fires simulation. Model simulations were run from April 1 through September 30 of each year. The first 10 days of the model simulations (April 1 – 10) are treated as model spin-up days and are not analyzed.

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[1] Simon, H., Beidler, J., Baker, K.R., Henderson, B.H., Fox, L., Misenis, C., Campbell, P., Vukovich, J., Possiel, N., Eyth, A. (2025) Expedited modeling of burn events results (EMBER): A screening-level dataset of 2023 ozone fire impacts in the US, *Data in Brief*, 58, 111208. https://doi.org/10.1016/j.dib.2024.111208.

[2] US EPA Office of Research and Development. (2024). CMAQ (5.5). Zenodo. https://doi.org/10.5281/zenodo.13883210.

[3] Zero out modeling refers to scenarios where the model is run without certain emissions sources (*e.g.* emissions are "zeroed out". This allows for the quantification of pollutant concentrations that would have occurred in a hypothetical scenario where the emissions sources did not exist. In the EMBER dataset, fire zero out simulations produce estimates of ozone concentrations that would have existed if the fires had not occurred.

[4] Agricultural burning is treated as an anthropogenic emissions sector within the U.S. for these simulations but is grouped with prescribed and wildfires in Mexico and Canada (2021 only).

The model simulations were run using a 36-km × 36-km grid resolution on a domain covering the contiguous U.S. and large portions of Canada and Mexico as show in Figure 1. The model set-up used 35 vertical layers extending up to 0.999 Pa.

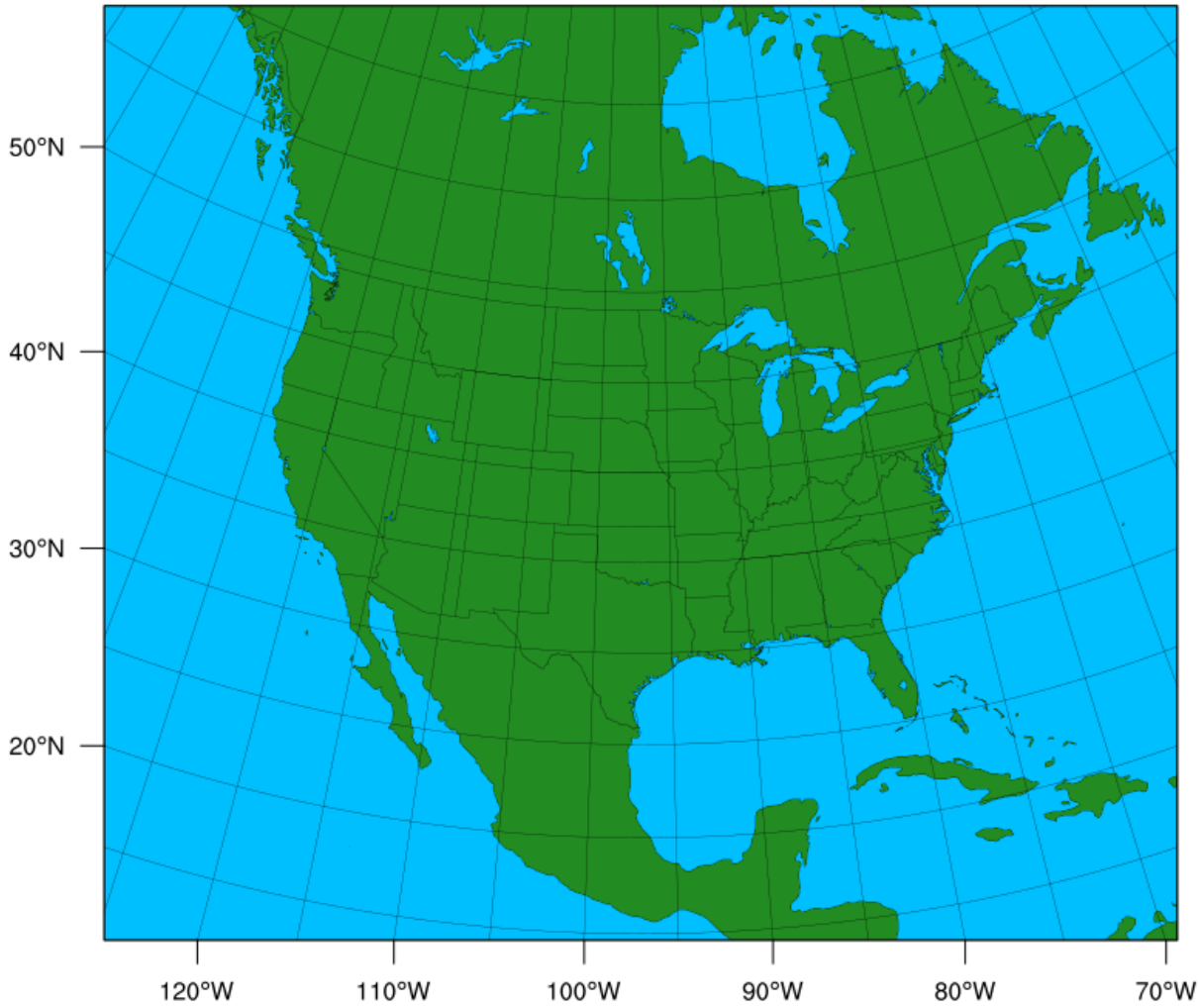

Figure 1: 36-km resolution modeling domain used for the EMBER simulations.

The following CMAQ configuration options were used for all simulations:

- Atmospheric transport
    - M3DRY dry deposition scheme
    - No bi-directional ammonia flux
    - Weather Research & Forecasting (WRF) Pleim-Xu land-surface model
- Gravitational settling option enabled enhanced ozone deposition over seawater disabled Inline emissions calculations
    - Biogenic Emission Inventory System version 4 (BEIS4)
    - Windblown dust emissions disabled

    - Inline lightning nitric oxide (NO) emissions with data from the World Wide Lightning Location Network (WWLLN)
- Chemistry and aerosol treatment
    - Carbon Bond 6 Revision 5 (CB6r5) chemical mechanism
    - 7th Generation Aerosol Module (AERO7) aerosol module: non-volatile primary organic aerosol; no potential combustion secondary organic aerosol formation
    - Ground surface nitrous acid (HONO) chemistry turned on

2.2 Meteorology input data

The 2023 EMBER modeling created meteorological CMAQ input files using the NOAA-EPA Atmosphere Chemistry Coupler (NACC) online portal[5]. This portal allowed the users to define a model domain of interest (*e.g.*, spatial extent, horizontal layer structure, grid resolution and projection) and automated the creation of CMAQ meteorological input files based on outputs from NOAA's Global Forecast System (GFS) Model for the specified domain. The online portal has since been taken offline however, the code for the NACC processor is still available from NOAA and can be downloaded and compiled on offline computer systems. The offline NACC was run to create CMAQ meteorological inputs for 2021, 2022, 2024 and 2025. All model years used outputs from the NOAA GFS Model with Finite-Volume Cubed-Sphere Dynamical Core (FV3) retrieved from the NOAA data server. The GFS model output files run from 12Z to 12Z while the CMAQ model runs daily from midnight to midnight GMT. Consequently, every two days of NACC files were concatenated and then subset in order to create CMAQ meteorological input files covering the midnight to midnight GMT time period. The same meteorological input files were used for the base and zero out simulations in each year.

2.3 Initial and Boundary Conditions

The chemical initial and boundary conditions for CMAQ were derived from NASA's Goddard Earth Observing System Composition Forecast (GEOS-CF) global model.[6] GEOS-CF simulations (version 1) have been computed for 2018 to present day and [7]. GEOS-CF integrates meteorology and emissions include both anthropogenic and natural emissions. Natural emissions include fires from the Quick

[5] https://www.arl.noaa.gov/research/surface-atmosphere-exchange-home/tools-and-products/nacc-nacc-cloud/; Campbell, P.C., Tang, Y., Lee, P., Baker, B., Tong, D., Saylor, R., Stein, A., Huang, J., Huang, H.-C., Strobach, E., McQueen, J., Pan, L., Stajner, I., Sims, J., Tirado-Delgado, J., Jung, Y., Yang, F., Spero, T.L., Gilliam, R.C. (2022) Development and evaluation of an advanced National air quality forecasting capability using the NOAA Global Forecast System version 16, *Geosci. Model Dev.*, 15, pp. 3281-3313, 10.5194/gmd-15-3281-2022.

[6] Keller, C. A., Knowland, K. E., Duncan, B. N., Liu, J., Anderson, D. C., Das, S., ... & Pawson, S. (2021) Description of the NASA GEOS composition forecast modeling system GEOS-CF v1. 0. *Journal of Advances in Modeling Earth Systems*, *13*(4), e2020MS002413.

[7]Knowland, K.E., C.A. Keller, and R. Lucchesi, 2022: File Specification for GEOS-CF Products. GMAO Office Note No. 17 (Version 1.3), 54 pp, available from https://gmao.gsfc.nasa.gov/gmao-products/geos-cf/

Fire[8] (QFED) v2.4. The fire emissions from QFED are most relevant when fires are near the CMAQ boundary (*e.g.*, Northern Canada) and transported into the domain. GEOS-CF provides global near real-time atmospheric composition estimates (hindcasts and forecasts) for pollutants such as ozone (O_3), carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and fine particulate matter ($PM_{2.5}$), at a horizontal resolution of approximately 25 km by 25 km. For CMAQ, the hindcast was used to supply lateral boundary conditions. This was done by mapping the nearest GEOS-CF grid cell to each boundary cell around the CMAQ domain perimeter. Data were extracted from hourly meteorological (met), chemistry (chm), and extended GEOS-Chem chemistry (xgc) files[9] through GMAO's OpenDAP server. The GEOS-CF species were then mapped to CMAQ's cb6r3ae7 chemical mechanism species using the geoscf2bc or aqmbc package[10]. Initial conditions were created for April 1 of 2021, 2022, 2024, and 2025. Boundary conditions were created for each day of the 2021, 2022, 2024, and 2025 modeled episodes for the 36 km resolution domain described above and for the EPA's typical 35 vertical layer structure (surface to 5000 Pa on the WRFv4 hybrid vertical coordinate).

2.4 Emissions inputs

2.4.1 Fire emissions

For all EMBER years, 2021-2022 and 2024-2025, the EPA developed model ready wildland fire emissions for the U.S., Canada, and Mexico. Wildland fire emissions estimates in the U.S. and Canada followed methods consistent with the process described in the technical support documentation of the 2022v2 emissions modeling platform[11]. For 2021 and 2022 fires, wildland fire emissions were obtained from the year-specific EPA modeling platforms[12]. These retrospective inventories leveraged datasets that were not available for the expedited 2023-2025 EMBER model years. For the 2024 and 2025 U.S. wildland fire inventories, wildland fire perimeter information was obtained from the Wildland Fire Interagency Geospatial Services (WFIGS) current interagency fire perimeters dataset, while Canada wildland fire perimeter

[8] Darmenov, A. S., & da Silva, A. (2015) The Quick Fire Emissions Dataset (QFED)—Documentation of versions 2.1, 2.2 and 2.4. Technical report series on Global Modeling and Data Assimilation, NASA//TM-2015-104606 (Vol. 38, p. 212). https://ntrs.nasa.gov/api/citations/20180005253/downloads/20180005253.pdf.

[9] https://opendap.nccs.nasa.gov/dods/gmao/geos-cf

[10] https://github.com/barronh/geoscf2bc; https://github.com/barronh/aqmbc

[11] Eyth, A., Seltzer, K., Vukovich, J., Farkas, C., Godfrey, J., Dayton, L., & Dietrich, Y. (2025) Technical Support Document (TSD): Preparation of Emissions Inventories for the 2022v2 North American Emissions Modeling Platform (EPA-454/B-25-002). US EPA Retrieved from https://www.epa.gov/system/files/documents/2025-12/2022v2_emismod_tsd_base_december2025.pdf.

[12] Eyth, A., Vukovich, J., Farkas, C., Godfrey, J., Seltzer, K., & Dietrich, Y. (2024) Technical Support Document (TSD): Preparation of Emissions Inventories for the 2021 North American Emissions Modeling Platform (EPA-454/B-24-011). US EPA Retrieved from https://www.epa.gov/system/files/documents/2025-06/2021_emismod_tsd_october2024.pdf.; Eyth, A., Seltzer, K., Vukovich, J., Farkas, C., Godfrey, J., Dayton, L., & Dietrich, Y. (2025) Technical Support Document (TSD): Preparation of Emissions Inventories for the 2022v2 North American Emissions Modeling Platform (EPA-454/B-25-002). US EPA Retrieved from https://www.epa.gov/system/files/documents/2025-12/2022v2_emismod_tsd_base_december2025.pdf.

information was obtained from the National Burned Area Composite (NBAC) geospatial dataset. The wildland fire perimeter data were reconciled with NOAA Hazard Mapping System (HMS) satellite detections using a modified python version of SmartFire 2. Emissions estimates were calculated from the fused wildland fire activity using the series of fuel loading, consumption, and emissions calculations modules in BlueSky pipeline. Fuel loading for locations in Canada was obtained by mapping Canada's Fuel Behavior Prediction (FBP) fuel beds to Fuel Characteristic Classification System (FCCS) loadings.

Fire emissions from Mexico were developed from the Fire INventory from NCAR (FINN). The 2021 and 2022 fires from Mexico used FINN v1.5 daily point emissions estimates[13], while the 2024 and 2025 used FINN v2.5[14] with newly developed speciation of organic gases that aligned with the emissions factor change from v1.5 to v2.5.

2.4.2 Other emissions sectors

The 2021 and 2022 EMBER simulations used the same anthropogenic emissions files that were used for the 2023 EMBER simulation which were based on the EPA's 2018v2 emissions inventory.[15] This inventory included emissions from area sources, point sources, onroad mobile sources, nonroad mobile sources, and commercial marine vessels. Representative 2018 day-of-week emissions files were used for each month of the simulation period. Model simulations for each day in 2021 and 2022 used the appropriate representative day-of-week and month emissions files as shown in Table 1 of the 2023 EMBER journal article.[16]

The 2024 and 2025 EMBER simulations use the same general procedure for anthropogenic emissions except that these simulations used emissions from the newly released 2022v2 emissions modeling platform.[17] In addition to the source categories listed above for the 2021 and 2022 simulations, the 2024 and 2025 simulations also include anthropogenic emissions from agricultural burning. Table 1 shows the 2022 emissions files that were applied to 2024 and

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[13] Wiedinmyer, C., Akagi, S. K., Yokelson, R. J., Emmons, L. K., Al-Saadi, J. A., Orlando, J. J., and Soja, A. J.: The Fire INventory from NCAR (FINN): a high resolution global model to estimate the emissions from open burning, Geosci. Model Dev., 4, 625–641, https://doi.org/10.5194/gmd-4-625-2011, 2011.

[14] Wiedinmyer, Christine et al. (2023). The Fire Inventory from NCAR version 2.5: an updated global fire emissions model for climate and chemistry applications. 16(13). https://doi.org/10.5194/gmd-16-3873-2023.

[15] Eyth, A., Vukovich, J., Farkas, C., Godfrey, J., & Seltzer, K. (2023) Technical Support Document (TSD): Preparation of Emissions Inventories for the 2018v2 North American Emissions Modeling Platform (EPA-454/B-23-003). US EPA Retrieved from https://www.epa.gov/system/files/documents/2024-02/2018v2_emismod_tsd_sep2023_508_0.pdf.

[16] Simon, H., Beidler, J., Baker, K.R., Henderson, B.H., Fox, L., Misenis, C., Campbell, P., Vukovich, J., Possiel, N., Eyth, A. (2025) Expedited modeling of burn events results (EMBER): A screening-level dataset of 2023 ozone fire impacts in the US, *Data in Brief*, 58, 111208. https://doi.org/10.1016/j.dib.2024.111208.

[17] Eyth, A., Seltzer, K., Vukovich, J., Farkas, C., Godfrey, J., Dayton, L., & Dietrich, Y. (2025) Technical Support Document (TSD): Preparation of Emissions Inventories for the 2022v2 North American Emissions Modeling Platform (EPA-454/B-25-002). US EPA Retrieved from https://www.epa.gov/system/files/documents/2025-12/2022v2_emismod_tsd_base_december2025.pdf.

2025 days by day-of-week and month. Along with the mapping described in Table 1, emissions from 2022 holidays were also mapped to the same holiday in 2024 and 2025 (for instance July 4, 2022, emissions were used for July 4, 2024, and July 4, 2025, simulation days regardless of which day of the week those holidays fell on). Additionally, for 2024 and 2025 Continuous Emissions Monitoring System (CEMS) data were leveraged to provide year and day-specific emissions from the subset of large point sources for which these data are available. The hourly generation unit-specific CEMS emissions data were retrieved from the EPA Clean Air Market Program Data website[18] and prepared for CMAQ consistent with the 2022v2 emissions modeling platform methods described elsewhere[19].

Table 1: Days from the 2022 emissions files used as the representative day for each day of the week and the month in 2024 and 2025.

Month	Monday	Tuesday-Friday	Saturday	Sunday
April	Apr 4, 2022	Apr 5, 2022	Apr 9, 2022	Apr 10, 2022
May	May 2, 2022	May 3, 2022	May 7, 202	May 8, 2022
June	Jun 6, 2022	Jun 7, 2022	Jun 11, 2022	Jun 12, 2022
July	Jul 11, 2022	Jul 12, 2022	Jul 16, 2022	Jul 17, 2022
August	Aug 8, 2022	Aug 9, 2022	Aug 13, 2022	Aug 14 ,2022
September	Sep 12, 2022	Sep 13, 2022	Sep 17, 2022	Sep 18, 2022

Natural emissions from biogenic emissions and soil NO were calculated within the model simulations using BEIS4[20]. Inline lightning NO emissions were calculated during the model simulation[21].

2.5 Ambient monitoring data

Ambient maximum daily 8-hour average (MDA8) ozone and 24-hour average $PM_{2.5}$ values reported to the EPA's Air Quality System (AQS) database and certified by the reporting agency for calendar years

[18] https://campd.epa.gov/data/bulk-data-files.

[19] Eyth, A., Seltzer, K., Vukovich, J., Farkas, C., Godfrey, J., Dayton, L., & Dietrich, Y. (2025) Technical Support Document (TSD): Preparation of Emissions Inventories for the 2022v2 North American Emissions Modeling Platform (EPA-454/B-25-002). US EPA Retrieved from https://www.epa.gov/system/files/documents/2025-12/2022v2_emismod_tsd_base_december2025.pdf.

[20] https://github.com/USEPA/CMAQ/wiki/CMAQ-Release-Notes:-Emissions-Updates:-BEIS-Biogenic-Emissions; Bash, J. O., Baker, K. R., and Beaver, M. R. (2016) Evaluation of improved land use and canopy representation in BEIS v3.61 with biogenic VOC measurements in California, *Geosci. Model Dev.,* 9, 2191–2207, https://doi.org/10.5194/gmd-9-2191-2016.; Pouliot, G. and Bash, J. (2015) Updates to Version 3.61 of the Biogenic Emission Inventory System (BEIS). Presented at Air and Waste Management Association conference, Raleigh, NC, 2015.

[21] Kang, D., Hogrefe, C., Sarwar, G., East, J.D., Madden, J.M., Mathur, R., Henderson, B.H. (2022) Assessing the Impact of Lightning NOx Emissions in CMAQ Using Lightning Flash Data from WWLLN over the Contiguous United States, *Atmosphere (Basel)* 13, 1248, doi: 10.3390/atmos13081248.

2021, 2022, and 2024[22] were used to compile paired modeled and observed data files that are matched in space and time. The paired data files are used to create tables and plots of the EMBER datasets and to calculate model evaluation statistics. Ambient MDA8 ozone and 24-hr $PM_{2.5}$ values reported to AQS for calendar year 2025 were retrieved on March 16, 2026 and used to compile similar paired modeled and observed data files. The May 1, 2026 data certification deadline for calendar year 2025 data had not yet passed the date of retrieval, so these data are considered preliminary. We believe that the use of preliminary data is appropriate for the purpose of feeding a screening tool such as EMBER; however, we caution that the 2025 EMBER observed values may include missing data or values that are flagged or updated in the final certified 2025 AQS dataset for some monitoring sites.

3. Known Issues

- For 2021 and 2022, the simulations were configured to use the Pleim-Xiu land surface model, but the meteorological inputs were from the Noah land surface model. This inconsistency affected the deposition algorithms due to misclassified soil types. For more information, see CMAQ issue 237.[23] Testing was conducted using the original 2023 EMBER case to quantify the impact of this inconsistency on base simulation MDA8 ozone. Those tests found that in most U.S. locations, the largest average base simulation MDA8 differences across all April through September 2023 days was less than 0.5 ppb. On a small number of days, differences in base simulation MDA8 above 0.5 ppb were found across Texas and along the Louisiana-Mississippi border. This inconsistency was corrected for the 2024 and 2025 EMBER simulations.
- Initial and boundary conditions were created for the 36 km resolution domain shown in Figure 1 and for the EPA's typical 35 vertical layer structure (surface to 5000 Pa on the WRFv4 hybrid vertical coordinate). The EMBER simulations actually extend higher to 0.999 Pa. The difference in model-top height in the atmosphere between the boundary conditions and the CMAQ model simulations mostly affects the upper troposphere and not the fire contribution. The same initial and boundary conditions were used for the base and zero out simulations in each year.

4. Summary model statistics

MDA8 ozone data from the base model simulations were paired in space and time with ambient MDA8 ozone data described in section 2.5. Density scatter plots for each year comparing the base simulation modeled MDA8 ozone values with measured values are provided in Figure 2 which show comparable model performance across years with the model generally capturing measured values.

[22] Available from: https://aqs.epa.gov/aqsweb/airdata/download_files.html
[23] https://github.com/USEPA/CMAQ/issues/237

Standard model performance statistics[24] were calculated for the April 11 – September 30 modeled time-period on a regional basis[25] for each year. Model performance statistics for 2021, 2022, 2024, and 2025 are reported in Tables 2 through 5. Normalized mean bias (NMB), normalized mean error (NME), and correlation (r) are very similar to model performance statistics for the 2023 EMBER simulation[26] and are also in the range of model performance reported across studies published in the scientific literature[27].

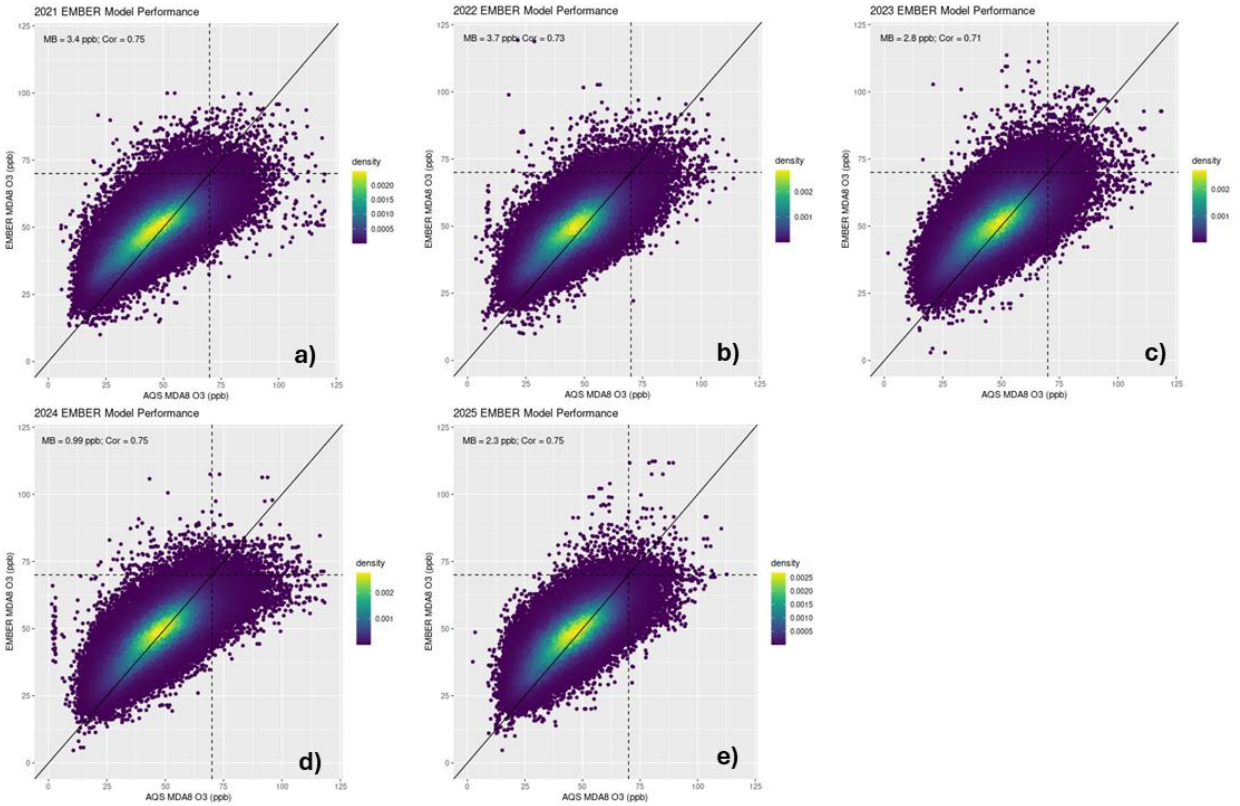

Figure 2: Density scatter plots comparing EMBER base simulation modeled MDA8 ozone (ppb) (y-axis) to measured MDA8 ozone at AQS monitoring locations (ppb) (x-axis) for a) 2021, b) 2022, c) 2023 (from Simon et al., 2025), d) 2024 and e) 2025. Comparisons are provided across all simulated days from April 11through September 30 of each year.

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[24] Simon, H., Baker, K.R., Phillips, S. (2012) Compilation and interpretation of photochemical model performance statistics published between 2006 and 2012. *Atmos. Environ*., 61, 124-139, 10.1016/j.atmosenv.2012.07.012.

[25] Regional definitions based on States included in NOAA climate regions (https://www.ncei.noaa.gov/access/monitoring/reference-maps/us-climate-regions):
Northeast = CT, DE, ME, MD, MA, NH, NJ, NY, PA, RI, VT; Upper Midwest = IA, MI, MN, WI; Ohio Valley = IL, IN, KY, MO, OH, TN, WV; Southeast = AL, FL, GA, NC, SC, VA; Northern Rockies and Plains = MT, NE, ND, SD, WY; South = AR, KS, LA, MS, OK, TX; Southwest = AZ, CO, NM, UT; Northwest = ID, OR, WA; West = CA, NV

[26] Simon, H., Beidler, J., Baker, K.R., Henderson, B.H., Fox, L., Misenis, C., Campbell, P., Vukovich, J., Possiel, N., Eyth, A. (2025) Expedited modeling of burn events results (EMBER): A screening-level dataset of 2023 ozone fire impacts in the US, *Data in Brief*, 58, 111208. https://doi.org/10.1016/j.dib.2024.111208.

[27] Simon, H., Baker, K.R., Phillips, S. (2012) Compilation and interpretation of photochemical model performance statistics published between 2006 and 2012. *Atmos. Environ*., 61, 124-139, 10.1016/j.atmosenv.2012.07.012.; Emery, C., Liu, Z., Russell, A.G., Odman, M.T., Yarwood, G., Kumar, N. (2017) Recommendations on statistics and benchmarks to assess photochemical model performance. *J Air Waste Manag. Assoc*, 67 (5), 582-598, 10.1080/10962247.2016.1265027.

Table 2: Model performance statistics for 2021 base EMBER simulations for April 11 – September 30 MDA8 ozone

Region	NMB (%)	NME (%)	r
Northeast	13.7	18.2	0.76
Upper Midwest	3.8	12.5	0.75
Ohio River Valley	12.0	15.5	0.76
Southeast	20.9	22.6	0.83
Northern Rockies	-1.7	11.7	0.71
South	15.2	20.1	0.79
Northwest	2.1	14.7	0.65
West	0.6	15.3	0.72
Southwest	-7.0	11.7	0.57

Table 3: Model performance statistics for 2022 base EMBER simulations for April 11 – September 30 MDA8 ozone

Region	NMB (%)	NME (%)	r
Northeast	12.6	16.5	0.76
Upper Midwest	6.4	13.9	0.76
Ohio River Valley	11.9	16.0	0.72
Southeast	19.2	20.8	0.81
Northern Rockies	2.2	10.3	0.65
South	10.7	18.1	0.76
Northwest	9.7	17.4	0.60
West	1.9	13.8	0.77
Southwest	-5.2	11.7	0.54

Table 4: Model performance statistics for 2024 base EMBER simulations for April 11 – September 30 MDA8 ozone

Region	NMB (%)	NME (%)	r
Northeast	5.1	12.4	0.81
Upper Midwest	3.3	11.1	0.79
Ohio River Valley	6.2	11.5	0.76
Southeast	9.2	14.1	0.82
Northern Rockies	-1.9	11.0	0.70
South	6.8	15.0	0.78
Northwest	1.6	14.0	0.72
West	-6.0	15.3	0.70
Southwest	-9.4	12.5	0.60

Table 5: Model performance statistics for 2025 base EMBER simulations for April 11 – September 30 MDA8 ozone

Region	NMB (%)	NME (%)	r
Northeast	7.7	14.0	0.78
Upper Midwest	4.9	12.9	0.79
Ohio River Valley	10.5	14.4	0.76
Southeast	14.1	17.4	0.79
Northern Rockies	2.2	10.4	0.75
South	10.2	16.2	0.80
Northwest	2.0	12.6	0.74
West	-3.7	13.1	0.76
Southwest	-6.6	11.1	0.61

5. Available data products

EMBER results are browsable through the Qlik web application available on the EPA's Exceptional Events Analysis and Visualization Tools webpage.[28] The EMBER viewer includes a downloadable master data table that provides daily data by ozone monitoring site. For each site-day with ambient ozone data, the table includes the monitored MDA8 ozone value, the modeled MDA8 ozone value, the modeled MDA8 ozone impacts from all fires, and the modeled MDA8 ozone impacts from fires from Canada and Mexico. The table also provides metadata such as State, county, core based statistical areas (CBSA), and nonattainment area name for each monitor. Data can be sorted or filtered by any of the data fields. The EMBER viewer also includes the following plot types which can be viewed or downloaded:

- Regional-daily maps showing modeled MDA8 ozone concentrations from the base and zero fire simulations, as well as maps of simulated MDA8 ozone impacts from all fires. Figure 3 provides an example of this figure type for the West region on August 27, 2021.
- Regional-daily maps showing gridded base simulation ground-level MDA8 ozone and monitored ozone at AQS monitors. Figure 4 provides an example of this figure type for the West region on August 27, 2021.
- Regional-daily maps showing gridded base simulation ground-level 24-hour average $PM_{2.5}$ concentrations and monitored $PM_{2.5}$ concentrations at AQS monitors. Figure 5 provides an example of this figure type for the West region on August 27, 2021.
- Monitor-level timeseries plots that provide modeled observed MDA8 ozone values along with total simulated fire impacts on MDA8 ozone for every AQS ozone monitor with preliminary data. Figure 3 provides an example of this figure type for AQS monitor ID 60670011 in Sacramento, CA in 2021.

In addition to the EMBER results available through the EPA website, model input and output files are provided through Amazon Web Services.[29] Model inputs include complete sets of emissions inputs, meteorology, and initial and boundary conditions used in the EMBER model simulations. Model outputs include IOAPI files of gridded daily layer 1 MDA8 ozone and 24-hour average $PM_{2.5}$ concentrations.

[28] https://www.epa.gov/air-quality-analysis/exceptional-events-analysis-and-visualization-tools.

[29] The EPA's EMBER dataset is available through Amazon Web Service's Open Data program: https://registry.opendata.aws/.

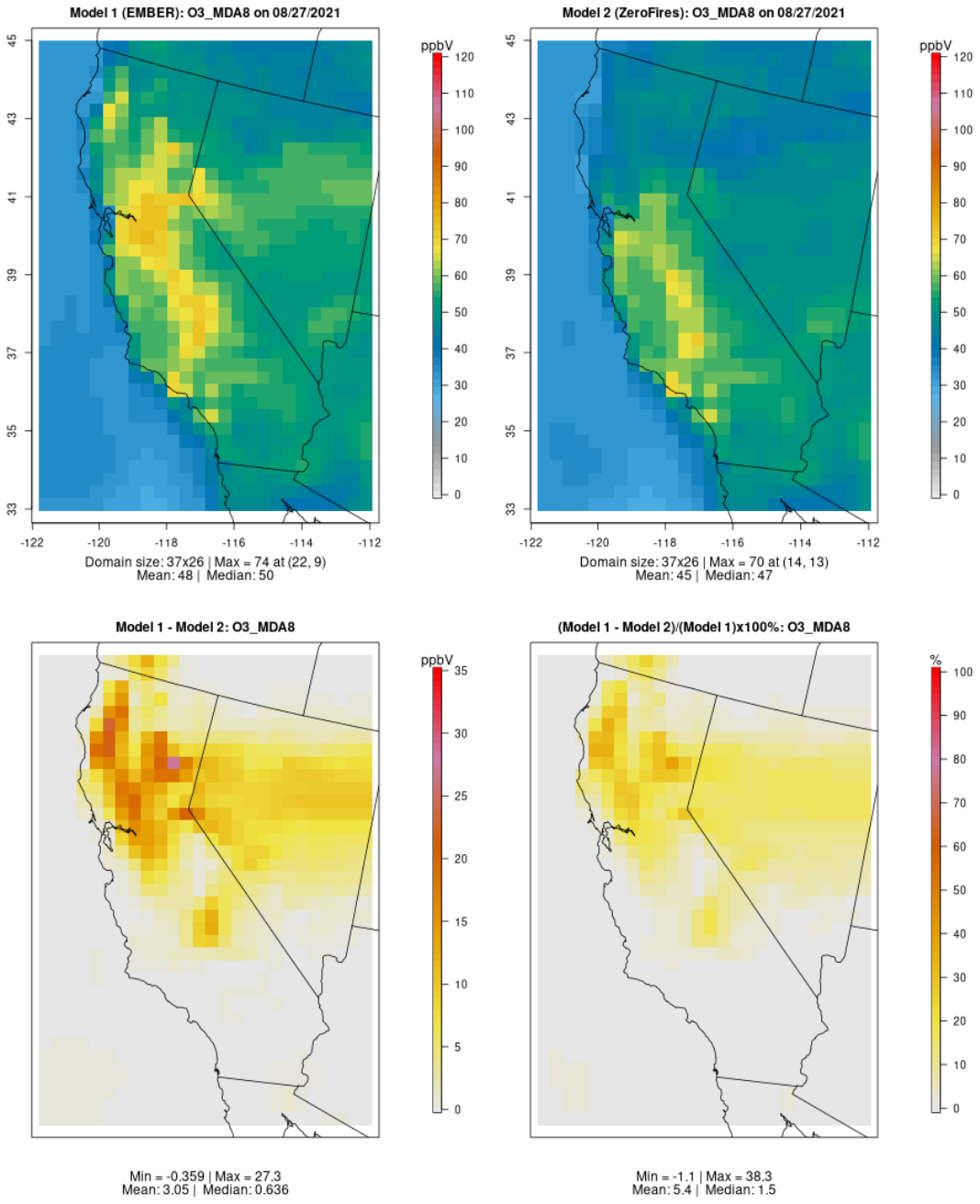

Figure 3: Ozone fire impacts modeled in EMBER on August 27, 2021, in the West region. MDA8 ozone concentration (ppb) modeled in the base EMBER simulation (top left); MDA8 ozone (ppb) modeled in the EMBER simulation without and fire emissions from the U.S., Canada, and Mexico (Zero Fires) (top right); absolute impact of fire emissions on MDA8 ozone concentration (ppb) calculated as EMBER – Zero Fires (bottom left); and relative impact of fire emissions on MDA8 ozone concentration (%) calculated as 100 × (EMBER – Zero Fires)/EMBER (bottom right).

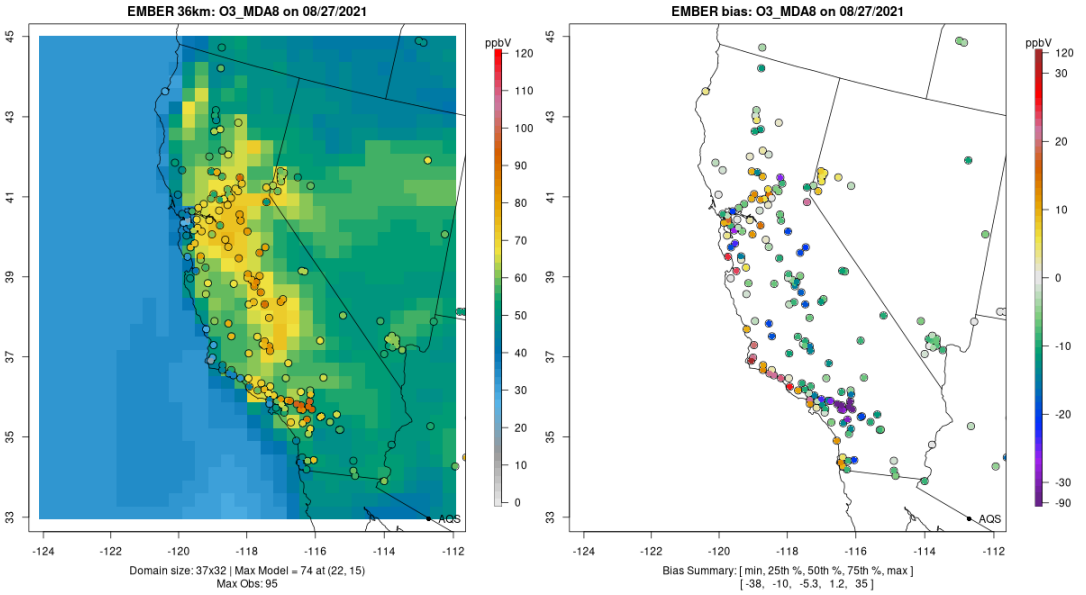

Figure 4: Measured MDA8 ozone concentrations (ppb) shown at monitoring locations (circles) on top of gridded modeled MDA8 ozone concentrations (ppb) for August 27, 2021, in the West region (left). Model bias MDA8 ozone concentration (ppb) at monitor locations calculated as model – observations for August 27, 2021 (right).

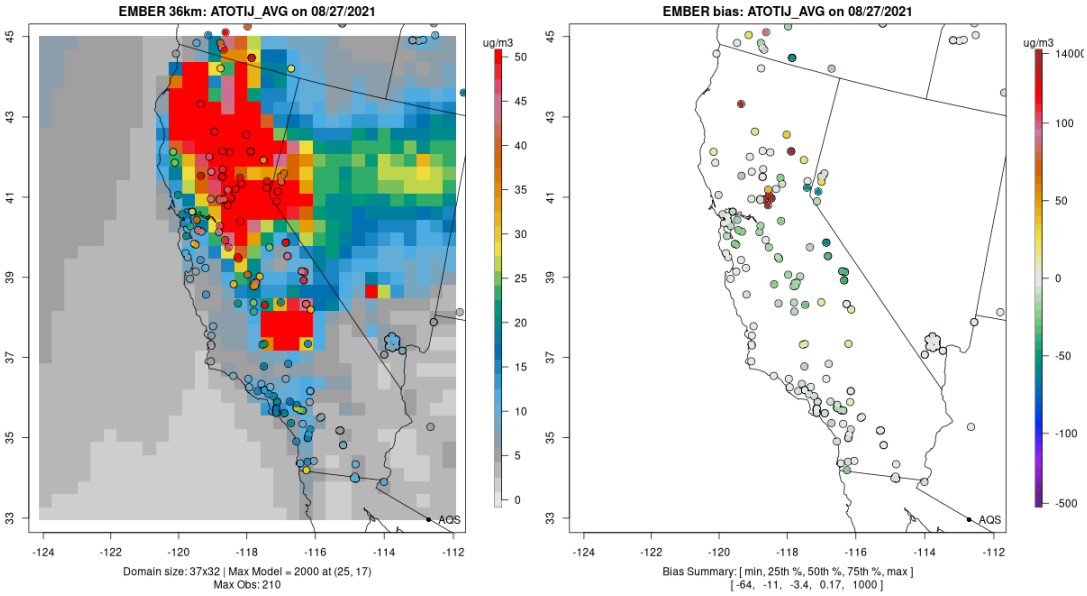

Figure 5: Measured 24-hour average $PM_{2.5}$ concentrations ($\mu g/m^3$) shown at monitoring locations (circles) on top of gridded modeled MDA8 ozone concentrations (ppb) for August 27, 2021, in the West region (left). Model bias 24-hour average $PM_{2.5}$ concentration ($\mu g/m^3$) at monitor locations calculated as model – observations for August 27, 2021 (right).

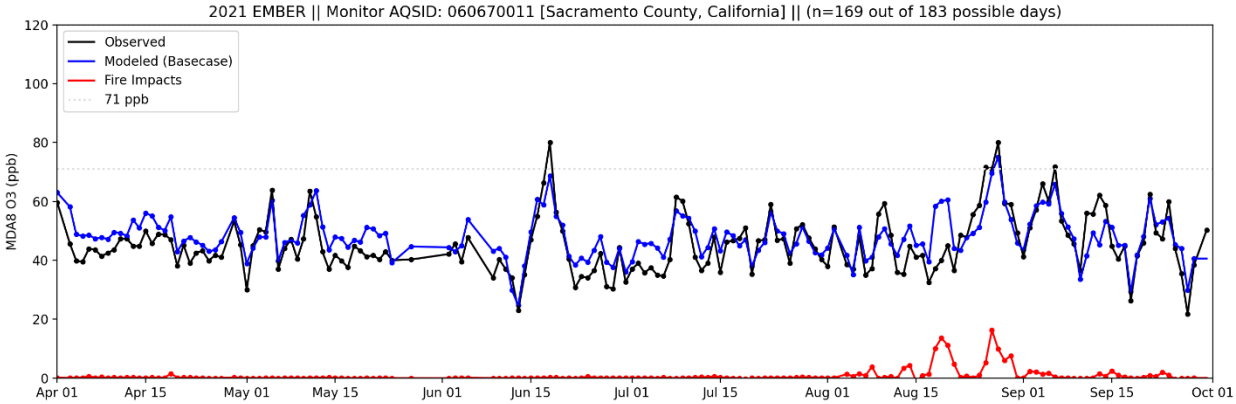

Figure 6: Observed (black) and modeled (blue) MDA8 ozone concentration (ppb) at Sacramento County, CA (AQS monitor ID: 060670011) from April - September 2021. Modeled U.S., Canada .and Mexico fire impacts on MDA8 ozone (ppb) shown in red. Any points above the dotted line at 71 ppb indicate MDA8 ozone values that exceeded the 2015 U.S. EPA National Ambient Air Quality Standards (NAAQS) level for ozone.