Technical Support Document (TSD)

Preparation of Emissions Inventories for the Version 7.1

2016 Hemispheric Emissions Modeling Platform

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Acronyms

AE5	CMAQ Aerosol Module, version 5, introduced in CMAQ v4.7
AE6	CMAQ Aerosol Module, version 6, introduced in CMAQ v5.0
NBAFM	Naphthalene, Benzene, Acetaldehyde, Formaldehyde and Methanol
BEIS	Biogenic Emissions Inventory System
BELD	Biogenic Emissions Land use Database
C1/C2	Category 1 and 2 commercial marine vessels
C3	Category 3 (commercial marine vessels)
CAP	Criteria Air Pollutant
CARB	California Air Resources Board
CB05	Carbon Bond 2005 chemical mechanism
CEMS	Continuous Emissions Monitoring System
Cl	Chlorine
CMAQ	Community Multiscale Air Quality
CMV	Commercial Marine Vessel
CO	Carbon monoxide
EBAFM	Ethanol, Benzene, Acetaldehyde, Formaldehyde and Methanol
ECA	Emissions Control Area
EEZ	Exclusive Economic Zone
EGU	Electric Generating Units
EIS	Emissions Inventory System
EPA	Environmental Protection Agency
EMFAC	Emission Factor (California's onroad mobile model)
FF10	Flat File 2010
FIPS	Federal Information Processing Standards
FHWA	Federal Highway Administration
HAP	Hazardous Air Pollutant
HCl	Hydrochloric acid
Hg	Mercury
IMO	International Marine Organization
MCIP	Meteorology-Chemistry Interface Processor
MOVES	Motor Vehicle Emissions Simulator
NEI	National Emission Inventory
NESCAUM	Northeast States for Coordinated Air Use Management
NESHAP	National Emission Standards for Hazardous Air Pollutants
NH_3	Ammonia
NIF	NEI Input Format
NLCD	National Land Cover Database
nm	nautical mile
NOAA	National Oceanic and Atmospheric Administration
NO_X	Nitrogen oxides
ORD	EPA's Office of Research and Development
$PM_{2.5}$	Particulate matter less than or equal to 2.5 microns
PM_{10}	Particulate matter less than or equal to 10 microns
ppb, ppm	Parts per billion, parts per million
RBT	Refinery to Bulk Terminal
RWC	Residential Wood Combustion
RVP	Reid Vapor Pressure
SCC	Source Classification Code

SMARTFIRE Satellite Mapping Automated Reanalysis Tool for Fire Incident Reconciliation
SMOKE Sparse Matrix Operator Kernel Emissions
SO_2 Sulfur dioxide
SOA Secondary Organic Aerosol
TOG Total Organic Gas
TSD Technical support document
VOC Volatile organic compounds
WRF Weather Research and Forecasting Model

1 Introduction

The U.S. Environmental Protection Agency (EPA) developed an air quality emissions modeling platform for hemispheric modeling with the Community Multiscale Air Quality (CMAQ) for the year 2016. This emission modeling platform represents an update to the 2011 platform described by Eyth et al. (2016). Similar to that work, this platform uses publicly available emissions that cover the globe and integrates these emissions with regional inventories to create a single consistent platform.

The hemispheric modeling platform includes the following components:

- In the United States, Canada, and Mexico, emissions are based on the 2016 alpha platform for regional scale air quality modeling. Details regarding the North America portion of the hemispheric emissions platform are provided in the 2016 v7.1 (also known as alpha) platform Technical Support Document).
- Outside North America, fire emissions are from the Fire Inventory from NCAR (FINN) for the year 2016. This includes wildfires, prescribed burning, and agricultural fires.
- In China, anthropogenic emissions excluding fires and carbon monoxide are from an emissions dataset provided by Tsinghua University (THU) for year 2015.
- Outside of North America and China, anthropogenic emissions excluding fires use the Hemispheric Transport of Air Pollution (HTAP) emissions inventory, version 2. HTAP emissions are for the year 2010, and are adjusted to year 2014 using factors derived from the Community Emissions Data System (CEDS).
- Biogenic emissions in most of North America are equivalent to those from the regional alpha platform and are generated by the BEIS model. Elsewhere in the modeling domain, biogenic emissions are from the Model of Emissions and Gases and Aerosols from Nature (MEGAN).

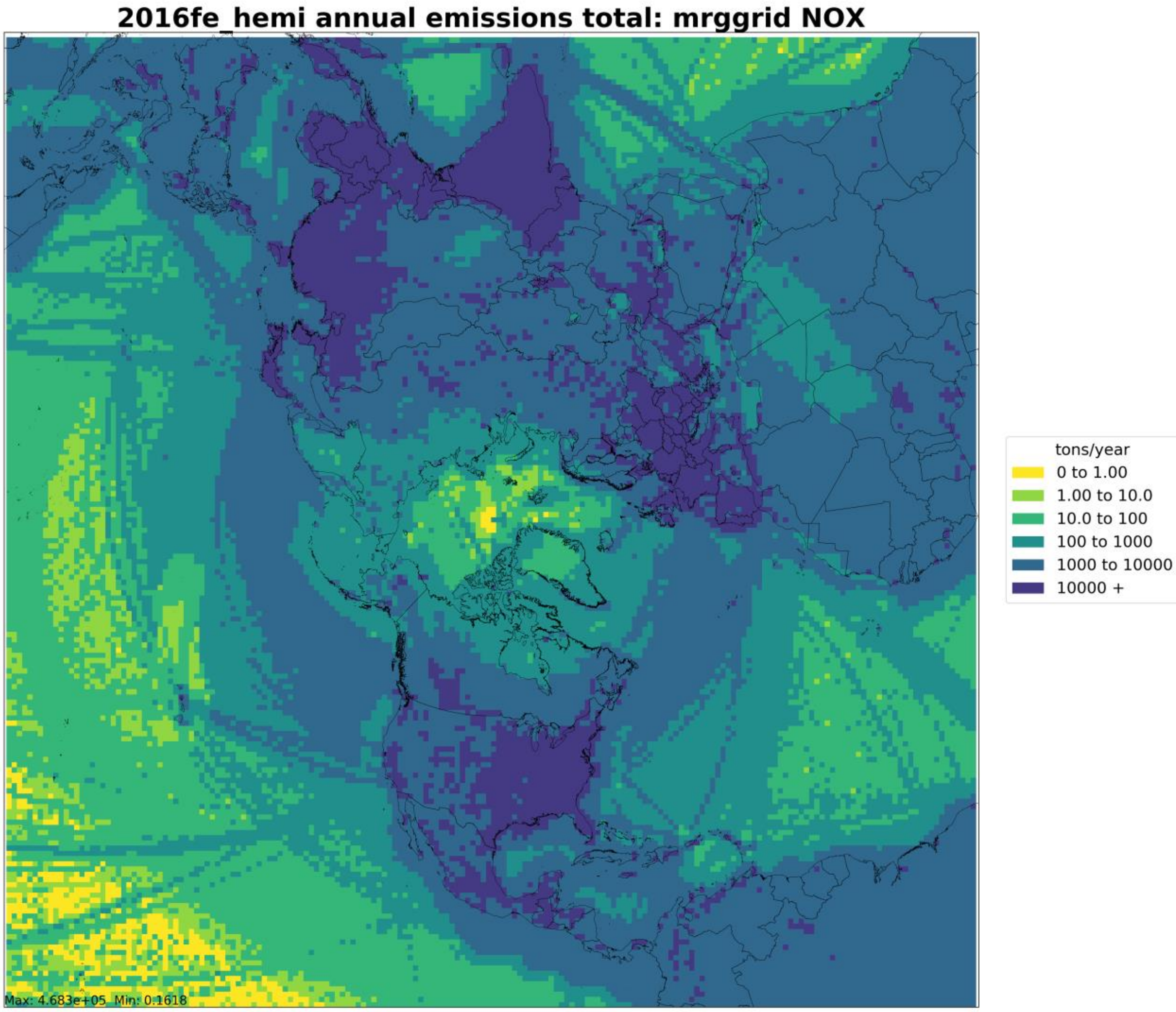
Hemispheric air quality modeling is performed on a polar stereographic grid which is centered on the North Pole, extends south to the equator, and has an approximate resolution of 108-km by 108-km per grid cell. Table 1-1 includes the description (i.e., specification) of the hemispheric grid. Figure 1-1 shows a visualization of NOx emissions on the 108km hemispheric modeling grid.

Table 1-1. Description of the hemispheric platform grid

Common Name	Grid Cell Size	Description	Grid name	Parameters listed in SMOKE grid description (GRIDDESC) file: projection name, xorig, yorig, xcell, ycell, ncols, nrows, nthik*
Hemispheric 108km grid	108 km	Polar stereographic grid of the Northern Hemisphere	HEMI_108k	'POL_HEMI', -10098000, -10098000, 108.D3, 108.D3, 187, 187, 1

* Corresponds to PROJ4 definition "+proj=stere +lat_0=90.0 +lat_ts=45.0 +lon_0=-98.0 +y_0=10098000.0 +x_0=10098000.0 +a=6370000.0 +b=6370000.0 +to_meter=108000 +no_defs"

Figure 1-1. Sample plot of Emissions on the 108km hemispheric modeling grid (log-scale tons/day)



The Community Multiscale Air Quality (CMAQ) model was used to model ozone (O_3) and particulate matter (PM) for this project. CMAQ includes support for hemispheric modeling, sometimes referred to as H-CMAQ modeling, and can be used to develop boundary conditions (BCs) for regional scale air quality modeling. CMAQ requires hourly and gridded emissions of the following inventory pollutants: carbon monoxide (CO), nitrogen oxides (NO_X), volatile organic compounds (VOC), sulfur dioxide (SO_2), ammonia (NH_3), particulate matter less than or equal to 10 microns (PM_{10}), and individual component species for particulate matter less than or equal to 2.5 microns ($PM_{2.5}$). In addition, the Carbon bond version 6 (CB6) with chlorine chemistry used here within CMAQ allows for explicit treatment of the VOC HAPs naphthalene, benzene, acetaldehyde, formaldehyde and methanol (NBAFM) and includes anthropogenic HAP emissions of HCl and Cl. However, most emissions inventories in this platform outside of the United States do not include any HAP emissions.

The primary emissions modeling tool used to create the air quality model-ready emissions was the Sparse Matrix Operator Kernel Emissions (SMOKE) modeling system version 4.5 (SMOKE 4.5) with some updates. Most regional scale CMAQ modeling is performed with "inline" plume rise, in which plume rise calculations for point sources are performed by CMAQ using stack parameters and meteorology. However, because the HTAP and THU China inventories do not include information on individual stacks, it is not possible to run H-CMAQ with the inline plume rise option. Instead, we must create layered emissions within SMOKE by running the Laypoint program for sources with stack information, and by running the Layalloc program to apply a fixed vertical allocation to sectors which do not have stack information.

The hemispheric modeling platform includes multiple sets of model-ready emissions, or “cases”:

- An annual “base case” for year 2016, abbreviated 2016fe_hemi_cb6_16jh.
- An annual “spinup case” for year 2015, abbreviated 2016fe_spinup_cb6_15jh. H-CMAQ modeling is performed with an 8-month spinup period, and the emissions for the spinup period are based on an entirely separate emissions case specific to the year 2015. For quality assurance and for other modeling applications, the spinup case emissions were processed for all of 2015, not just for the 8-month period required for spinup of 2016 modeling.
- Several sensitivity runs in which one or more categories of emissions are zeroed out or modified, as described in Section 3.

The gridded meteorological model used to provide input data for the emissions modeling was developed using the Weather Research and Forecasting Model (WRF version 3.8, Advanced Research WRF core (Skamarock, et al., 2008). The WRF Model is a mesoscale numerical weather prediction system developed for both operational forecasting and atmospheric research applications. The WRF was run for 2015 and 2016 over the 108-km resolution hemispheric modeling domain with 44 vertical layers. The WRF run for this platform is given the EPA meteorological case label “16jh.” The full case name includes this abbreviation following the emissions portion of the case name to fully specify the name of the case as “2016fe_hemi_cb6_16jh.”

The CMAQ model requires hourly emissions of specific gas and particle species for the horizontal and vertical grid cells contained within the modeled region (i.e., modeling domain). To provide emissions in the form and format required by the model, it is necessary to “pre-process” the “raw” emissions (i.e., emissions input to SMOKE). In brief, the process of emissions modeling transforms the emissions inventories from their original temporal resolution, pollutant resolution, and spatial resolution into the hourly, speciated, gridded resolution required by the air quality model. Emissions modeling includes temporal allocation, spatial allocation, and pollutant speciation. For hemispheric modeling, emissions modeling also includes the vertical allocation of point sources.

The temporal resolutions of the emissions inventories input to SMOKE vary across sectors and may be hourly, daily, monthly, or annual total emissions. The spatial resolution may be individual point sources, county/province/municipio totals, or pre-gridded emissions and varies by sector. This section provides some basic information about the tools and data files used for emissions modeling as part of the modeling platform.

For most sectors, SMOKE version 4.5 was used to process the raw emissions inventories into emissions inputs for each modeling sector into a format compatible with CMAQ. For hemispheric modeling, plume rise is not calculated “inline” during CMAQ modeling; instead, the emissions output from SMOKE and input to CMAQ are 3-D emissions files and already have plume rise applied. For QA of the emissions modeling steps, emissions totals by specie for the entire model domain are output as reports that are then compared to reports generated by SMOKE on the input inventories to ensure that mass is not lost or gained during the emissions modeling process. Preparation of China emissions from the THU dataset (section 2.2), biogenic emissions from MEGAN (section 2.4.1), and lightning NOx emissions (section 2.4.2) was not performed in SMOKE, but with other utilities as described in the relevant sections below.

The chemical mechanism used for the 2014 platform is the CB6 mechanism (Yarwood, 2010). We used a particular version of CB6 that we refer to here as “CB6-CMAQ” that breaks out naphthalene (NAPH) from XYL and PAR as an explicit model species, resulting in model species NAPH and XYLMN instead of XYL, and revising PAR to remove the naphthalene portion (very small amount). CB6-CMAQ also uses SOAALK (Pye and Pouliot, 2012), a species produced from TOG speciation that is not used in CAMX. This platform generates the $PM_{2.5}$ model species associated with the CMAQ Aerosol Module version 6 (AE6).

Section 2 of this document describes the global inventories input to SMOKE and preparation of the emissions for air quality modeling. Section 3 outlines several sensitivity cases in which new sets of emissions were modeled with a portion of the emissions zeroed out. Data summaries are provided in Section 4.

2 Hemispheric Emission Inventories and Modeling Approaches

This section describes the emissions data and processing that make up the 2016 hemispheric platform, excluding the United States, Canada, and Mexico inventories that make up the corresponding regional modeling platform. Documentation for the North America portion of the platform is in the 2016 alpha platform TSD.

For the purposes of preparing the air quality model-ready emissions, the platform consists of several sectors for emissions modeling. The significance of an emissions modeling or platform “sector” is that the data are run through the SMOKE programs independently from the other sectors except for the final merge (Mrggrid). The final merge program combines the sector-specific gridded, speciated, hourly emissions together to create CMAQ-ready emission inputs.

Table 2-1 lists all sectors in the hemispheric platform and their data sources. For North America sectors originating from the alpha platform for regional modeling, only a brief description of the sector is offered here, with additional detail in the regional modeling TSD. The platform sector abbreviations are provided in italics. These abbreviations are used in the SMOKE modeling scripts, inventory file names, and throughout the remainder of this document. Most sectors which include global (e.g. HTAPv2) emissions include a “g_” prefix.

Table 2-2 provides a brief by-sector outline of the differences between the emissions used in the 2016 base case and the emissions used in the 2015 spinup case.

Table 2-1. Sectors for the 2016 hemispheric modeling platform

Platform Sector: *abbreviation*	**Data Source**	**Description and resolution of the data input to SMOKE**
U.S. EGUs: *ptegu*	Alpha Platform	Electric Generating Units (EGUs) from the US NEI. Annual resolution, with hourly resolution for sources that match Continuous Emission Monitoring (CEM) data.
U.S. point source oil and gas: *pt_oilgas*	Alpha Platform	Oil and gas production point sources from the US NEI. Includes emissions from oil rigs in the Gulf of Mexico. Annual resolution.
U.S. remaining non-EGU point: *ptnonipm*	Alpha Platform	All point sources from the US NEI not matched to the ptegu or pt_oilgas sectors. Annual resolution.

Platform Sector: *abbreviation*	**Data Source**	**Description and resolution of the data input to SMOKE**
U.S. agricultural: *ag*	Alpha Platform	Nonpoint livestock and fertilizer application emissions from the US NEI. Livestock includes ammonia and other pollutants (except PM2.5). County and annual resolution.
U.S. agricultural fires with point resolution: *ptagfire*	Alpha Platform	Agricultural fire sources that were developed by EPA as point sources for 2016. Daily resolution.
U.S. area fugitive dust: *afdust*	Alpha Platform	PM_{10} and $PM_{2.5}$ fugitive dust sources from the 2014NEIv2 nonpoint inventory; including building construction, road construction, agricultural dust, and road dust. The NEI emissions are reduced during modeling according to a transport fraction and a meteorology-based (precipitation and snow/ice cover) zero-out. Does not include onroad emissions in Alaska, Hawaii, Puerto Rico, or Virgin Islands (see othafdust sector). County and annual resolution.
U.S. biogenic: *beis*	Alpha Platform	Year 2016, hour-specific, grid cell-specific emissions generated from the BEIS3.61 model within SMOKE. Includes emissions in the Continental U.S. and portions of southern Canada and northern Mexico. Uses BELD v4.1 land use data.
Hemispheric biogenic: *g_biog*	MEGAN model	Year 2016, hour-specific, grid cell-specific emissions generated from the MEGAN model for the portion of the hemispheric modeling domain not covered by the BEIS sector.
U.S. Category 1, 2 CMV: *cmv_c1c2*	Alpha Platform	Category 1 (C1) and category 2 (C2) commercial marine vessel (cmv) emissions sources based on the 2014NEIv2 nonpoint inventory, with SO_2 emissions reduced by 90% for 2016. Includes emissions in U.S. State and Federal Waters. County and annual resolution.
U.S. Category 3 CMV: *cmv_c3*	Alpha Platform	Category 3 (C3) cmv emissions based on the 2014NEIv2 nonpoint inventory, converted to point sources, and with SO_2 emissions reduced by 90% for 2016. Includes emissions in U.S. State and Federal Waters only; CMV emissions beyond U.S. Federal Waters are in the g_ships sector. Annual resolution.
U.S. locomotives: *rail*	Alpha Platform	Rail locomotives emissions from the 2014NEIv2. County and annual resolution.
U.S. remaining nonpoint: *nonpt*	Alpha Platform	2014NEIv2 nonpoint sources not included in other platform sectors. County and annual resolution.
U.S. nonpoint source oil and gas: *np_oilgas*	Alpha Platform	2014NEIv2 nonpoint sources from oil and gas-related processes, projected to 2016. County and annual resolution.
U.S. Residential Wood Combustion: *rwc*	Alpha Platform	2014NEIv2 nonpoint sources from residential wood combustion (RWC) processes. County and annual resolution.
U.S. Nonroad: *nonroad*	Alpha Platform	2016 nonroad equipment emissions developed with the MOVES2014a model. MOVES was used for all states except California, which submitted their own emissions. County and monthly resolution.
U.S. Onroad: *onroad*	Alpha Platform	2016 onroad mobile source gasoline and diesel vehicles from moving and non-moving vehicles that drive on roads, along with vehicle refueling. Includes the following modes: exhaust, extended idle, auxiliary power units, evaporative, permeation, refueling, and brake and tire wear. For all states except California, developed using winter and summer MOVES emissions tables produced by MOVES2014a. Does not include onroad emissions in Alaska, Hawaii, Puerto Rico, or Virgin Islands (see onroad_can sector).

Platform Sector: ***abbreviation***	**Data Source**	**Description and resolution of the data input to SMOKE**
U.S. Onroad California: *onroad_ca_adj*	Alpha Platform	2016 California-provided CAP and metal HAP onroad mobile source gasoline and diesel vehicles submitted to the NEI, gridded and temporalized using MOVES2014a. Volatile organic compound (VOC) HAP emissions derived from California-provided VOC emissions and MOVES-based speciation.
U.S. point source fires: *ptfire*	Alpha Platform	Point source day-specific wildfires and prescribed fires for 2016 computed using SMARTFIRE2 and Blue Sky Framework for both flaming and smoldering processes (i.e., SCCs 281XXXX002). Smoldering is forced into layer 1 (by adjusting heat flux). Daily resolution.
Other North America fires: *ptfire_othna*	Alpha Platform	Point source day-specific wildfires and prescribed fires for 2016. Canada fires provided by Environment Canada, with data for missing months filled in using fires from the Fire INventory (FINN) from National Center for Atmospheric Research (NCAR) fires (NCAR, 2016 and Wiedinmyer, C., 2011). Fires in Mexico and Central America are from FINN. Daily resolution.
Canada dust sources: *othafdust*	Alpha Platform	Fugitive dust sources from Canada's 2013 and 2025 inventories (interpolated to 2016). A transport fraction adjustment is applied along with a meteorology-based (precipitation and snow/ice cover) zero-out. Also includes afdust emissions in Alaska, Hawaii, Puerto Rico, and Virgin Islands from 2014NEIv2. County and annual resolution.
Canada and Mexico point sources: *othpt*	Alpha Platform	Point sources from Canada's 2013 and 2025 inventories (interpolated to 2016) and Mexico's 2014 and 2018 inventories (interpolated to 2016), annual resolution.
Canada and Mexico nonpoint and nonroad: *othar*	Alpha Platform	Year 2016 Canada (province or sub-province resolution) emissions, interpolated from 2013 and 2025: monthly for agricultural ammonia, and nonroad sources; annual for rail, CMV and other nonpoint Canada sectors. Year 2016 Mexico (municipio resolution), interpolated from 2014 and 2018: annual nonpoint and nonroad mobile inventories.
Other non-NEI onroad sources: *onroad_can*	Alpha Platform	Monthly year 2016 Canada (province resolution or sub-province resolution, depending on the province) onroad mobile inventory, interpolated from 2013 and 2025. Also includes onroad emissions in Alaska, Hawaii, Puerto Rico, and Virgin Islands from 2014NEIv2.
Other non-NEI onroad sources: *onroad_mex*	Alpha Platform	Monthly year 2016 Mexico (municipio resolution) onroad mobile inventory, interpolated from 2014 and 2018.
Point source wildland fires outside North America: *g_ptfire*	FINN	Point source day-specific wildfires and prescribed fires for 2016 from the Fire INventory (FINN) from National Center for Atmospheric Research (NCAR) fires (NCAR, 2016 and Wiedinmyer, C., 2011). Includes all fires outside North America. Daily resolution.
Point source agricultural fires outside North America: *g_ptagfire*	FINN	Point source day-specific agricultural fires for 2016 from the Fire INventory (FINN) from National Center for Atmospheric Research (NCAR) fires (NCAR, 2016 and Wiedinmyer, C., 2011). Includes all fires outside North America. Daily resolution.
Agricultural emissions outside North America and China: *g_ag*	HTAP v2 + CEDS	Agricultural emissions outside North America and China, from the gridded HTAP version 2 dataset, agriculture sector. Year 2010 projected to 2014 using factors from CEDS dataset. Monthly resolution.

Platform Sector: *abbreviation*	**Data Source**	**Description and resolution of the data input to SMOKE**
Aircraft landing/takeoff emissions: *g_air_lto*	HTAP v2	Landing and takeoff emissions from aircraft, from the gridded HTAP version 2 dataset, air sector. Annual resolution.
Aircraft climbing and descent emissions: *g_air_cds*	HTAP v2	Climbing and descent emissions from aircraft, from the gridded HTAP version 2 dataset, air sector. Annual resolution.
Aircraft cruising emissions: *g_air_crs*	HTAP v2	Cruising emissions from aircraft, from the gridded HTAP version 2 dataset, air sector. Annual resolution.
Energy sector emissions outside North America and China: *g_energy*	HTAP v2 + CEDS	Energy sector emissions from the gridded HTAP version 2 dataset, excluding North America and China. Year 2010 projected to 2014 using factors from CEDS dataset. Monthly resolution.
Industry sector emissions outside North America and China: *g_industry*	HTAP v2 + CEDS	Industry sector emissions from the gridded HTAP version 2 dataset, excluding North America and China. Year 2010 projected to 2014 using factors from CEDS dataset. Monthly resolution.
Residential sector emissions outside North America and China: *g_residential*	HTAP v2 + CEDS	Residential sector emissions from the gridded HTAP version 2 dataset, excluding North America and China. Year 2010 projected to 2014 using factors from CEDS dataset. Monthly resolution.
Transport sector emissions outside North America and China: *g_transport*	HTAP v2 + CEDS	Transport sector emissions from the gridded HTAP version 2 dataset, excluding North America and China. Year 2010 projected to 2014 using factors from CEDS dataset. Monthly resolution.
Shipping emissions outside North America: *g_ships*	HTAP v2 + CEDS	Shipping emissions from the gridded HTAP version 2 dataset, ships sector. Excludes emissions in U.S. State and Federal Waters. Year 2010 projected to 2014 using factors from CEDS dataset. Annual resolution.
China fertilizer application: *china_agrf*	THU China	Fertilizer application emissions in China from the THU dataset. Annual resolution with hourly temporal profiles.
China livestock: *china_agrl*	THU China	Livestock emissions in China from the THU dataset. Annual resolution with hourly temporal profiles.
China domestic biofuel: *china_dobi*	THU China	Domestic biofuel emissions in China from the THU dataset. Annual resolution with hourly temporal profiles.
China domestic combustion: *china_docb*	THU China	Domestic combustion emissions in China from the THU dataset. Annual resolution with hourly temporal profiles.
China domestic fossil fuel: *china_dofu*	THU China	Domestic fossil fuel emissions in China from the THU dataset. Annual resolution with hourly temporal profiles.
China domestic solvent use: *china_doso*	THU China	Domestic solvent use emissions in China from the THU dataset. Annual resolution with hourly temporal profiles.
China other domestic: *china_doth*	THU China	Other domestic emissions in China from the THU dataset. Annual resolution with hourly temporal profiles.
China industry combustion: *china_incb*	THU China	Industrial combustion emissions in China from the THU dataset. Annual resolution with hourly temporal profiles.
China power plant: *china_ppcb*	THU China	Power plant emissions in China from the THU dataset. Annual resolution with hourly temporal profiles.

Platform Sector: *abbreviation*	Data Source	Description and resolution of the data input to SMOKE
China cement: *china_prce*	THU China	Cement process emissions in China from the THU dataset. Annual resolution with hourly temporal profiles.
China steel: *china_prir*	THU China	Steel process emissions in China from the THU dataset. Annual resolution with hourly temporal profiles.
China industrial solvent use: *china_prso*	THU China	Industrial solvent use emissions in China from the THU dataset. Annual resolution with hourly temporal profiles.
China other industrial: *china_prot*	THU China	Other industrial process emissions in China from the THU dataset. Annual resolution with hourly temporal profiles.
China transport off-road: *china_trof*	THU China	Off-road mobile emissions in China from the THU dataset. Annual resolution with hourly temporal profiles.
China transport on-road: *china_tron*	THU China	On-road mobile emissions in China from the THU dataset. Annual resolution with hourly temporal profiles.
Lightning NOx emissions: *lightning*	GEIA	Global NOx emissions from lightning strikes.

Table 2-2. Summary of emissions differences between 2015 spinup and 2016 base case emissions by sector

Platform Sector	2016 base case	2015 spinup case
afdust_adj	2014NEIv2, adjusted with 2016 meteorology	2014NEIv2, adjusted with 2015 meteorology
onroad	2016 activity / emission factors / meteorology	2015 activity / emission factors / meteorology
onroad_ca_adj	CARB inventory interpolated to 2016	CARB inventory interpolated to 2015
ag	2016 fertilizer + 2014NEIv2 livestock + 2016 met-based temporalization	2014NEIv2 fertilizer and livestock + 2015 met-based temporalization
cmv_c1c2	2014NEIv2 with SO_2 reduced by 90%	Same as 2016
cmv_c3	2014NEIv2 with SO_2 reduced by 90%	Same as 2016
nonpt	2014NEIv2	Same as 2016
nonroad	2016 inventory from MOVES2014a	Interpolation of 2014 and 2016 inventories from MOVES2014a
np_oilgas	2014NEIv2 projected to 2016	2014NEIv2 projected to 2015
rail	2014NEIv2	Same as 2016
rwc	2014NEIv2 + 2016 met-based temporalization	2014NEIv2 + 2015 met-based temporalization
othafdust	2013 and 2025 Canada, interpolated to 2016	2013 and 2025 Canada, interpolated to 2015
onroad_can	2013 and 2025 Canada, interpolated to 2016	2013 and 2025 Canada, interpolated to 2015
onroad_mex	2014 and 2018 Mexico, interpolated to 2016	2014 and 2018 Mexico, interpolated to 2015
othar	2013 and 2025 Canada, interpolated to 2016 2014 and 2018 Mexico, interpolated to 2016	2013 and 2025 Canada, interpolated to 2015 2014 and 2018 Mexico, interpolated to 2015
othpt	2013 and 2025 Canada, interpolated to 2016 2014 and 2018 Mexico, interpolated to 2016	2013 and 2025 Canada, interpolated to 2015 2014 and 2018 Mexico, interpolated to 2015
ptagfire	2016 point ag fire dataset	2015 point ag fire dataset
ptegu	2016 point inventory	2015 point inventory
ptnonipm	2016 point inventory	2015 point inventory
pt_oilgas	2016 point inventory, with remaining 2014 sources projected to 2016	2015 point inventory, with remaining 2014 sources projected to 2015
ptfire	2016 SMARTFIRE2 dataset	2015 SMARTFIRE2 dataset
g_ptfire	2016 FINN dataset	2015 FINN dataset

Platform Sector	2016 base case	2015 spinup case
ptfire_othna	2016 Environment Canada fires + FINN fires	2015 STI fires
beis	2016 biogenics	2015 biogenics
g_biog	2016 biogenics	2015 biogenics
g_ag	2010 HTAPv2 + 2014 CEDS projection	Same as 2016
g_ptagfire	2016 FINN dataset	2015 FINN dataset
g_air_cds	2010 HTAPv2	Same as 2016
g_air_crs	2010 HTAPv2	Same as 2016
g_air_lto	2010 HTAPv2	Same as 2016
g_energy	2010 HTAPv2 + 2014 CEDS projection	Same as 2016
g_industry	2010 HTAPv2 + 2014 CEDS projection	Same as 2016
g_residential	2010 HTAPv2 + 2014 CEDS projection	Same as 2016
g_ships	2010 HTAPv2 + 2014 CEDS projection	Same as 2016
g_transport	2010 HTAPv2 + 2014 CEDS projection	Same as 2016
lightning	Gridded lightning NOx dataset	Same as 2016
All China sectors (china_*)	2015 China THU	Same as 2016

Documentation for the North America emissions sectors is provided in the 2016 alpha platform for regional modeling TSD. The following sectors concern the emissions inventories for the portions of the hemispheric platform that are not part of the regional modeling platform.

2.1 Global HTAP version 2

The Hemispheric Transport of Air Pollution Version 2 inventory, or HTAPv2 inventory, is the basis for most emissions in the platform outside of North America and China. HTAP inventories are available here: http://edgar.jrc.ec.europa.eu/htap_v2/

Each HTAP sector is mapped to one or more platform sectors as outlined in Table 2-3. The representative dates column indicates whether emissions are processed for every day of the year ("All"); seven days per month, one for each day of the week ("Week"); four days per month, corresponding to Mondays, other WeekDays, Saturdays, and Sundays ("MWDSS"); or for a single average day per month ("Aveday").

Table 2-3. HTAP sector mappings to platform sectors

HTAP sector	Platform sector(s)	Inventory resolution	Pollutants	Representative dates
Air	g_air_cds g_air_crs g_air_lto	Annual	CO, NOx, PM_{10}, $PM_{2.5}$, BC (PEC), OC (POC), SO_2, NMVOC	All
Ships	g_ships	Annual	CO, NOx, PM_{10}, $PM_{2.5}$, BC (PEC), OC (POC), SO_2, NMVOC	All
Energy	g_energy	Monthly	CO, NH_3, NOx, PM_{10}, $PM_{2.5}$, BC (PEC), OC (POC), SO_2, NMVOC	All
Industry	g_industry	Monthly	CO, NH_3, NOx, PM_{10}, $PM_{2.5}$, BC (PEC), OC (POC), SO_2, NMVOC	All
Transport	g_transport	Monthly	CO, NH_3, NOx, PM_{10}, $PM_{2.5}$, BC (PEC), OC (POC), SO_2, NMVOC	Week
Residential	g_residential	Monthly	CO, NH_3, NOx, PM_{10}, $PM_{2.5}$, BC (PEC), OC (POC), SO_2, NMVOC	MWDSS
Ag	g_ag	Monthly	NH_3	Aveday

Hemispheric emissions totals from each HTAP sector are provided in Table 2-4. These emissions totals include CEDS projections (see section 2.1.5), do not include emissions in North America or China that were zeroed out (see section **Error! Reference source not found.**), and are domain-wide for the 108km hemispheric modeling domain.

Table 2-4. Emissions totals by HTAP sector, 108km hemispheric domain, tons/year for 2016

sector	CO	NH3	NOX	PM10	PM2.5	SO2	VOC
g_ag		27,053,284					
g_air_cds	134,140		1,089,169	18,439	18,439	92,194	31,552
g_air_crs	179,798		1,457,442	24,682	24,682	123,425	42,107
g_air_lto	116,928		282,723	2,350	2,350	26,785	4,415
g_energy	8,597,034	71,485	14,168,795	4,951,791	2,077,552	26,978,678	884,267
g_industry	132,095,290	992,589	6,997,163	6,873,446	3,563,763	16,333,374	38,620,852
g_residential	232,141,408	4,546,822	4,344,817	15,661,354	11,074,589	3,478,108	33,272,813
g_ships	1,175,509		12,078,998	1,207,008	1,207,008	6,633,296	628,816
g_transport	99,498,142	189,347	24,530,368	1,827,155	1,678,990	1,621,702	23,083,023

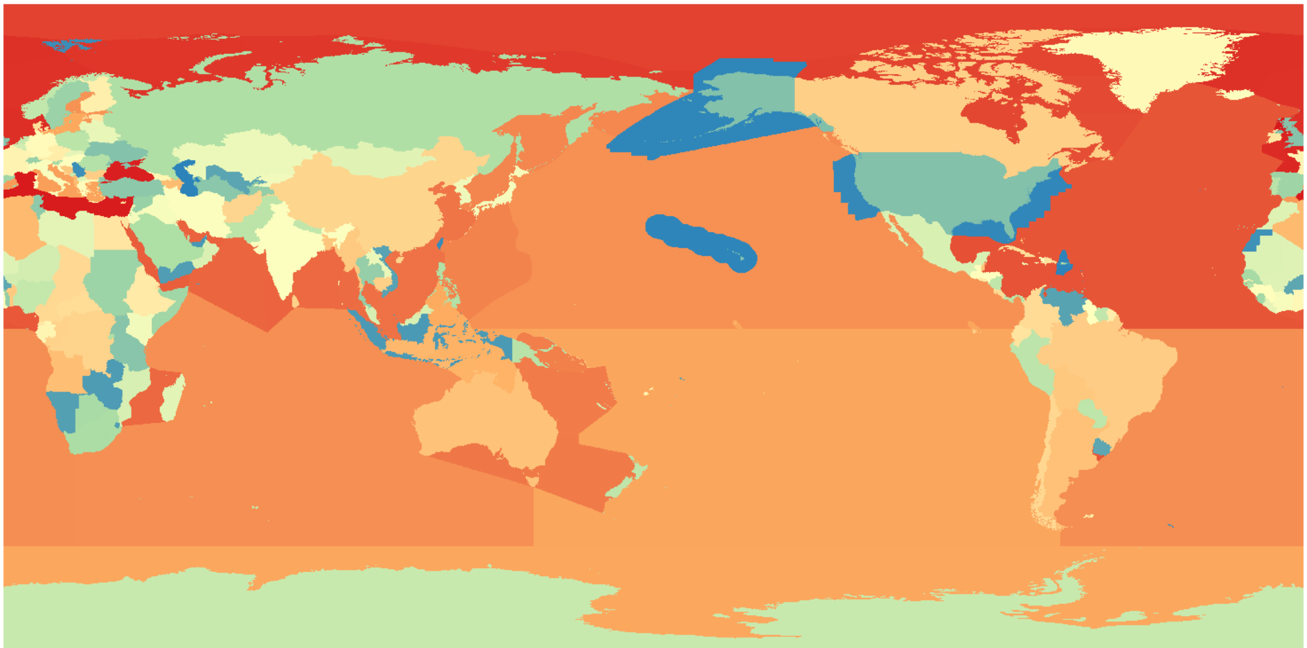
2.1.1 Spatial Allocation

The HTAP dataset includes gridded annual and monthly datasets on a global 0.1° latitude by 0.1° longitude grid. Spatial allocation of these inventories in SMOKE consists of two steps. First, in the SMOKE program Smkinven, each 0.1° by 0.1° point on the global grid is mapped to a country code (GEOCODE) and a time zone using a file called the GRIDMASK. Then, the SMOKE program Grdmat spatially reallocates emissions from the global input grid to the 108km polar stereographic grid used for air quality modeling.

The GRIDMASK file is a gridded file on the same 0.1° by 0.1° global grid and maps each point on the grid to a GEOCODE and a time zone. Smkinven maps each point in the gridded inventory data to a GEOCODE, enabling calculation of national emissions totals, and application of country-specific projections or controls. GEOCODEs are defined not only for each country, but also for distinct bodies of water, e.g. the North Atlantic Ocean, Gulf of Mexico, Caribbean Sea, and so on. The time zone information is used by the SMOKE program Temporal to apply diurnal profiles with the correct time zone offsets. Time zones with a 30-minute offset (e.g. Newfoundland, India) are rounded to the nearest hour in SMOKE modeling.

A plot of the GEOCODEs in the GRIDMASK file is shown in Figure 2-1, in which distinct GEOCODEs appear as different colors.

Figure 2-1. Map of **GEOCODE Country Codes**



2.1.2 Chemical Speciation

HTAP inventories include the following pollutants: "no methane VOC" (NMVOC); black carbon (BC, mapped to model species PEC); organic carbon (OC, mapped to model species POC); total $PM_{2.5}$; and other standard CAPs (CO, NH3, NOx, PM10, SO2). HTAP inventories do not include any HAP emissions.

Unlike regional modeling which uses emissions inventories with SCCs, HTAP inventories do not include more detailed information beyond the sector total for each point on the grid by month and pollutant. Therefore, we must apply sector-average speciation profiles to each HTAP sector. For VOC, average speciation profiles for HTAP sectors for the CB6 chemical mechanism were developed from the 2011 emissions modeling platform. In that platform, U.S. SCCs were each mapped to one of the HTAP sectors, and then speciated emissions were summed by HTAP sector group to develop an average VOC profile for each HTAP sector. Since the HTAP inventories specify "NMVOC" instead of "VOC", these average profiles do not include methane (CH4), but do include other species which may be considered part of TOG but not VOC, such as ethane (ETHA). There is no VOC-to-TOG conversion prior to speciation like there is in traditional emissions modeling, since these average profiles are computed on the basis of (NM)VOC.

For $PM_{2.5}$ speciation, the HTAP dataset includes emissions for black carbon, organic carbon, and total $PM_{2.5}$. In SMOKE modeling, we map black carbon to the model species PEC, and organic carbon to the model species POC. Since PEC and POC are also part of total $PM_{2.5}$, we must subtract PEC and POC from total $PM_{2.5}$ in order to prevent a double count. Prior to SMOKE modeling, an additional set of gridded inventory files is generated for PM2_5_OTH (other PM2.5), which is equal to total $PM_{2.5}$ minus PEC minus POC. Then, PM2_5_OTH is speciated using speciation profiles which map to the remaining

PM species needed for CMAQ modeling. It is still necessary for SMOKE to use total $PM_{2.5}$ for the sole purpose of calculating PMC (PM10 minus total $PM_{2.5}$), but only PM2_5_OTH is mapped to PM model species other than PEC, POC, and PMC. Similar to the VOC speciation profiles, speciation of PM2_5_OTH uses sector-specific average profiles.

For all HTAP sectors, NOx is speciated to NO and NO2 using a 90/10 split. Emissions for the HONO species are not created outside of North America. The SULF species is calculated as a percentage of SO2 in the HTAP energy, industry, and residential sectors.

2.1.3 Temporal Allocation

Similar to with chemical speciation, each HTAP sector has a single set of temporal profiles (weekly and diurnal, and also monthly for sectors without monthly inventories) that is applied to the entire sector. These temporal profiles were estimated using North American source-specific examples and best judgement. Because different countries celebrate different holidays, there are no considerations for holiday temporalization in the HTAP sectors.

Similar to some North America sectors, some HTAP sectors are processed with representative dates, as specified in Table 2-3 (above). For example, the HTAP ag sector uses flat day-of-week temporalization, and so for the g_ag sector, we process emissions for one representative day per month. The aircraft, energy, industry, and ships sectors are processed for every day to support plume rise, as discussed in the next section.

The weekly and diurnal temporal profiles for HTAP sectors are shown in Figures 2-2 and 2-3. The HTAP air and ships sectors each use a flat monthly temporal profile, while the other HTAP sectors have monthly inventories and do not use monthly temporal profiles.

Figure 2-2. Day-of-week temporal profiles for HTAP sectors

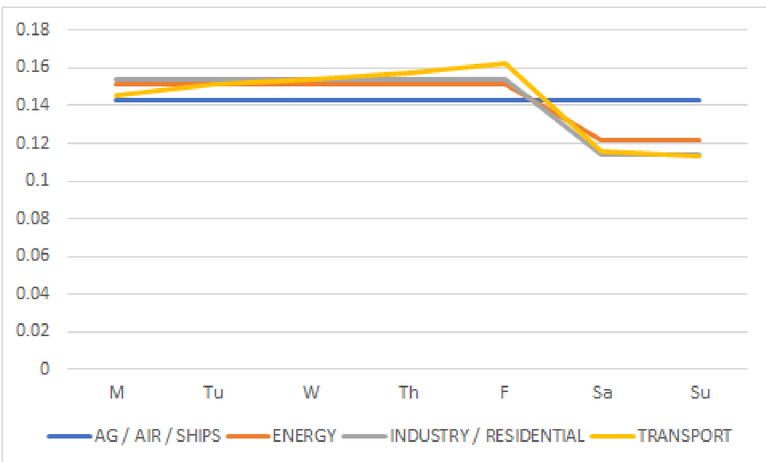
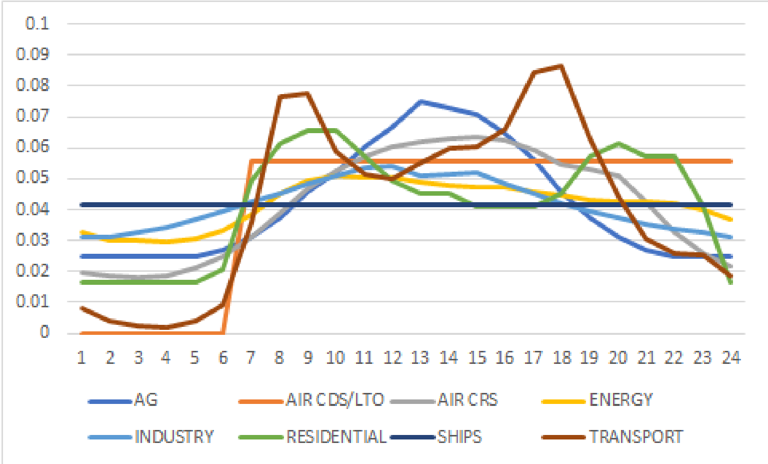


Figure 2-3. Hour-of-day temporal profiles for HTAP sectors

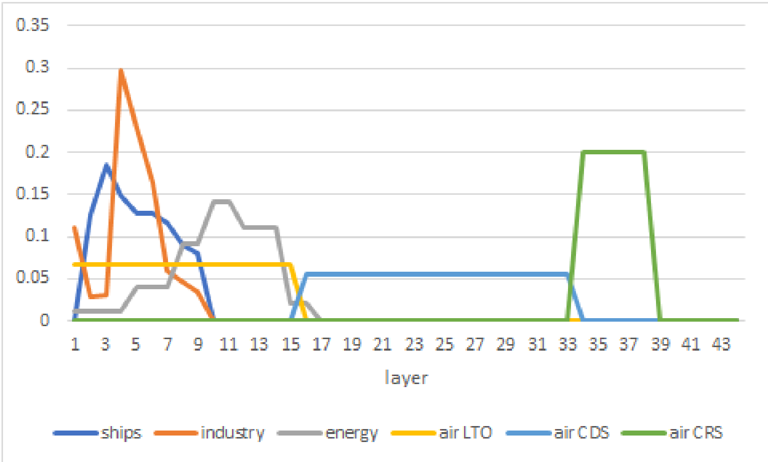


2.1.4 Vertical Allocation

Unlike in North America sectors, HTAP inventories do not include stack parameters or other information which can be used to estimate plume rise for point sources. This means we cannot run CMAQ with inline plume rise, and must apply vertical allocation in SMOKE to all sectors. In North America, we can use the Laypoint program to calculate plume rise using stack parameters and meteorology. Without stack parameters, we cannot do that for HTAP sectors; instead, we apply vertical profiles on a sector-wide basis.

Figure 2-4 shows the vertical profiles applied to HTAP sectors. Among HTAP sectors, only the aircraft, energy, industry, and ships sectors have a vertical profile applied. For ag, residential, and transport, all emissions remain in Layer 1.

Figure 2-4. Layer fractions for HTAP sectors



Vertical profiles are applied using the SMOKE program Layalloc. First, the SMOKE program Smkmerge generates daily emissions with everything in a single layer, and then the Layalloc program splits the emissions from Smkmerge into vertical layers. Layer fractions are input to Layalloc in the following format, where “bottom” and “top” are layer heights in meters:

layer,bottom,top,fraction

1,0,20,0.06667
2,20,44,0.06667
3,44,70,0.06667
4,70,101,0.06667
….
41,14388,15345,0
42,15345,16394,0
43,16394,17565,0
44,17565,18874,0

Layalloc requires that the bottom and top of each layer be specified in the layer fraction file, and applies layer fractions according to those layer heights, not according to the layer number in the first column. Layer heights are not constant, but vary according to meteorology. Our layer fraction files use layer heights averaged across the year. Because layer heights vary temporally and spatially, the actual layer fractions as applied by Layalloc are not constant. This means that occasionally, a small amount of emissions may appear in a layer with a 0% layer fraction. For example, the layer fractions for aircraft cruising emissions allocate 20% of the emissions to each of five layers from 34 to 38; but because of varying layer heights, Layalloc does allocate a small amount of emissions to layers 33 and 39.

2.1.5 Projection to 2014 via CEDS

The HTAP version 2 inventory represents emissions for the year 2010, which is six years prior to the model year for this project. A projection of the HTAP emissions to a year as close to 2016 as possible was desired.

Data from the Community Emissions Data System, or CEDS, includes emissions totals for the years 2010 and 2014, among other years, by country and emissions sector. Emissions totals for years after 2014 were not available at the time of this study, so 2014 was used as a reasonable approximation for 2016.

Table 2-5 shows how CEDS sectors were mapped to HTAP sectors. CEDS data is available at a much finer resolution than the aggregate sectors listed in this table, but because adjustment factors can only be applied on a sector-wide basis in SMOKE, we could not apply projection factors at a finer resolution than as shown in this table.

Table 2-5. Mapping of CEDS sectors to HTAP sectors

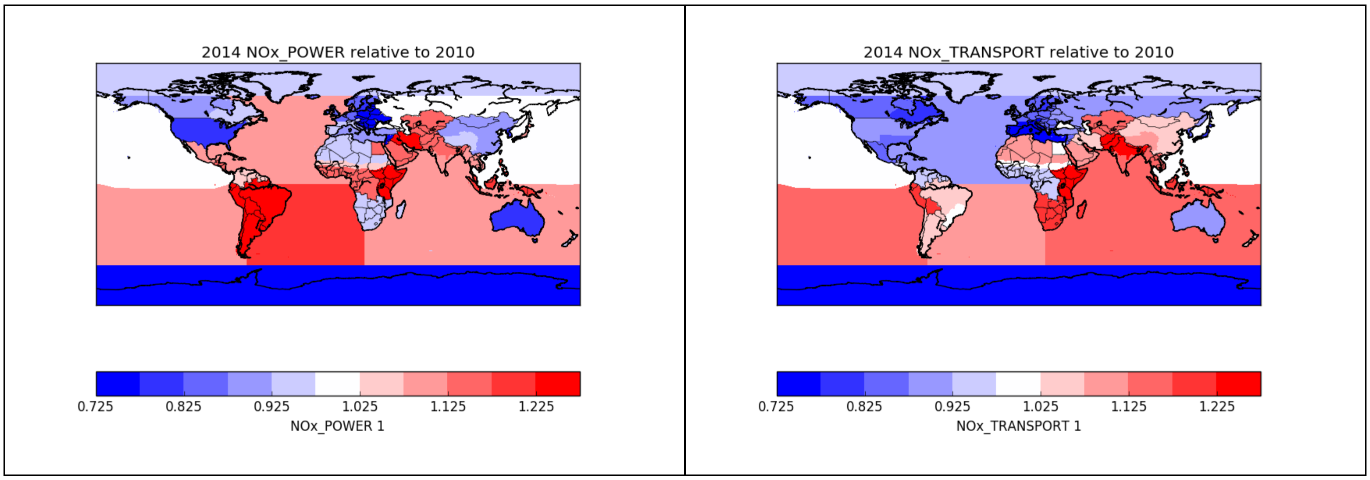
CEDS aggregate sector(s)	HTAP sector (SMOKE sector)
Agriculture	Agriculture (g_ag)
Power	Energy (g_energy)
Industry, Solvents	Industry (g_industry)
Residential, Waste	Residential (g_residential)
Ship	Ships (g_ships)
Transportation	Transport (g_transport)

HTAP projection factors for each country, HTAP/SMOKE sector, and pollutant were calculated using CEDS emissions totals for 2010 and 2014 (examples in Figure 2-5), and then converted into GCNTL format for application in SMOKE. Separate projection factors were calculated for PEC (BC), POC (OC), and total PM2.5, as well as for CO, NH3, NOX, SO2, and NMVOC. In China, we applied CEDS projection factors to HTAP emissions for carbon monoxide (CO) only, because the THU dataset does not include CO emissions. In the EdgarCHN sensitivity (see Section 23.1.9) CEDS factors were applied to

HTAP emissions for all pollutants in China. For the ships sector, because most shipping emissions take place over open water and not in a specific country, and because SO2 is the primary pollutant of interest with the ships sector, a global projection factor was applied to the entire domain for SO2 only. The CEDS dataset does not include emissions for aircraft, and so HTAP aircraft emissions were not projected.

Country-specific projection factors can be applied in SMOKE according to the GEOCODE for each country, with GEOCODEs mapped to a set of points in the gridded HTAP inventories using the GRIDMASK file. To limit the influence of unrealistically high or low projection factors from the CEDS dataset, projection factors were limited to a range of 0.5 (50% decrease) to 1.5 (50% increase).

Figure 2-5. Projection factors from year 2010 to 2014 for POWER(left) and TRANSPORT(right) sectors for NOx emissions derived from CEDS.



To prevent double counting of emissions with other datasets, a portion of the emissions from the HTAP datasets must be zeroed out. In North America, all HTAP emissions except for in-flight aircraft are zeroed out, to prevent a double count with the U.S., Canada, and Mexico inventories. In China, all HTAP emissions except for CO (all sectors), and except for aircraft and shipping (all pollutants), are zeroed out, to prevent a double count with the THU datasets. Zero-outs are implemented with a GCNTL file, which is read by the SMOKE program Cntlmat and applied to model-ready emissions by pollutant and country GEOCODE. The procedure for applying zero-outs is the same as the procedure for applying CEDS-based projection factors, except in the case of zero-outs, the "projection factor" is zero.

In most HTAP sectors, including ag, residential, transport, energy, and industry, we zeroed out emissions from the following GEOCODEs: United States, Canada, Mexico, and China (except CO). Puerto Rico, Virgin Islands, Hong Kong, and Macau have separate GEOCODEs from the United States and China, and were also zeroed out, as these areas were determined to overlap the U.S. and China datasets, respectively. Taiwan is not covered by the THU dataset and is not zeroed out.

Bodies of water which border the United States, Canada, and Mexico were also zeroed out in most HTAP sectors. This is because emissions from the HTAP dataset extend slightly into points that are assigned water GEOCODEs instead of land GEOCODEs in the GRIDMASK file, and zeroing out bodies of water adjacent to North America as well as the land areas prevents a "ring" of emissions from appearing along the North America coast. In China, to prevent THU China and HTAP emissions from occuring in the same grid cells, the GRIDMASK file was modified to ensure that any point covered by the THU China datasets is mapped to either the original China GEOCODE, or to a new GEOCODE called "China Coastline". In SMOKE, we then zeroed out both China and China Coastline emissions (except CO).

The HTAP ships and air sectors are handled differently with respect to zero-outs. For shipping, the U.S. CMV sectors (cmv_c1c2, cmv_c3) include emissions in U.S. state and federal waters, extending 200 nautical miles off the U.S. coastline. The original GRIDMASK file did not distinguish U.S. federal waters from non-federal waters, and so it was originally not possible to zero out HTAP ships emissions in the exact area covered by the cmv_c1c2 and cmv_c3 sectors. Previous hemispheric emissions modeling applications resolved this by dropping U.S. federal water emissions from the cmv_c1c2 and cmv_c3 sectors, but for this platform, use of U.S.-based emissions in federal waters was preferred over use of HTAP ships emissions. To facilitate this, additional GEOCODEs were added to the GRIDMASK file in U.S. state and federal waters. First, points in U.S. state waters that were originally assigned to a water GEOCODE (e.g. 034000 for Gulf of Mexico) were reassigned to the code 3100XX, where XX = the U.S. state FIPS code (e.g. 310012 for Florida). Second, points in U.S. federal waters that were originally assigned to a water GEOCODE were reassigned to the code 85X000, where X = a number from 1 through 7 corresponding to the FIPS code associated with each offshore zone (1 = North Pacific, 2 = South Pacific, 3 = Gulf Coast, 4 = East Coast, 5 = Alaska, 6 = Hawaii, 7 = Puerto Rico). When running the HTAP ships sector, we zero out all emissions from the U.S., Canada, and Mexico GEOCODEs, and also from all U.S. state and federal water GEOCODEs, but not from any bodies of water outside of U.S. federal waters. We do not zero out shipping emissions in or around China because the THU dataset does not include shipping.

The U.S. and Canada inventories include emissions from aircraft that are landing or taking off, which overlaps the HTAP air LTO sector. Therefore, in the g_air_lto sector, we zero out emissions over land in the United States and Canada. We do not zero out LTO emissions in Mexico, China, or over any bodies of water including U.S. federal waters. We do not zero out any emissions in the HTAP g_air_cds (climbing/descent) or g_air_crs (cruising) sectors, as the U.S. and Canada aircraft inventories do not include those categories of aircraft emissions.

2.2 THU China

Gridded annual emissions for China for the year 2015 were provided by Tsinghua University (THU) (Zhao et al., 2018,). The THU dataset includes emissions for 16 sectors, 15 of which are included in the platform. The THU dataset includes annual gridded emissions on a Lambert projection grid with 27km resolution; emissions for NH3, NOX, PM10, PM2.5, SO2, and VOC, including partial speciation; and temporal profiles which are used to generate hourly emissions.

The THU dataset emissions sectors, along with a mapping to the equivalent HTAP sectors, are listed in Table 2-6. We are not using the open burning sector emissions from THU. Fire emissions from the FINN dataset are preferred over the THU open burning emissions, primarily because the FINN data has better daily resolution. Note that the THU dataset does not overlap the HTAP aircraft or ships sectors. Annual emissions totals by sector for China are in Table 2-7.

The emissions files provided by Tsinghua University were annual files on a Lambert grid with 27km resolution with partial speciation. Conversion of these emissions to the format needed for air quality modeling was performed using standalone tools and not with the SMOKE model. First, the emissions were temporalized from annual to hourly; then, additional speciation and unit conversion was performed as needed; then, emissions were reallocated to the 108km hemispheric grid; and finally, the emissions were allocated vertically, depending on the sector.

Table 2-6. List of THU China sectors and equivalent HTAP sectors

THU China sector	Equivalent HTAP sector
AGRF (fertilizer application)	Agriculture
AGRL (livestock)	Agriculture
DOBI (domestic bio-fuel)	Residential
DOCB (domestic combustion)	Residential
DOFU (domestic fossil fuel)	Residential
DOSO (domestic solvent use)	Residential
DOTH (other domestic)	Residential
INCB (industry combustion)	Industry
PPCB (power plant)	Energy
PRCE (cement)	Industry
PRIR (steel)	Industry
PRSO (industry solvent use)	Industry
PROT (other industry process)	Industry
TROF (off-road transport)	Transport
TRON (on-road transport)	Transport
OPEN (open burning)	None; using FINN fires instead of THU fires

Table 2-7. Annual emissions totals by THU China sector, tons/year

China sector	NH3	NOX	PM10	PM2.5	SO2	VOC[1]
AGRF (fertilizer application)	4,105,865					
AGRL (livestock)	6,164,346					
DOBI (domestic bio-fuel)		247,159	1,535,996	1,487,994	37,311	247,159
DOCB (domestic combustion)						2,254,033
DOFU (domestic fossil fuel)		684,444	2,030,505	977,311	3,894,725	684,444
DOSO (domestic solvent use)						1,863,873
DOTH (other domestic)	741,314					213,655
INCB (industry combustion)		2,520,744	1,453,406	965,475	5,920,805	2,653,154
PPCB (power plant)		4,390,020	1,175,701	702,486	4,992,558	4,390,020
PRCE (cement)		2,100,046	1,370,862	757,175	1,005,509	2,100,046
PRIR (steel)		603,922	1,300,269	939,834	836,222	603,922
PRSO (industry solvent use)						5,792,690
PROT (other industry process)	353,494	2,389,083	1,591,475	1,014,461	1,881,593	7,557,787
TROF (off-road transport)		2,684,613	219,988	208,409	159,214	3,354,114
TRON (on-road transport)		8,385,993	405,461	384,119	22,164	15,460,059

[1]*VOC totals in this table are estimated from a sum of individual VOC species.*

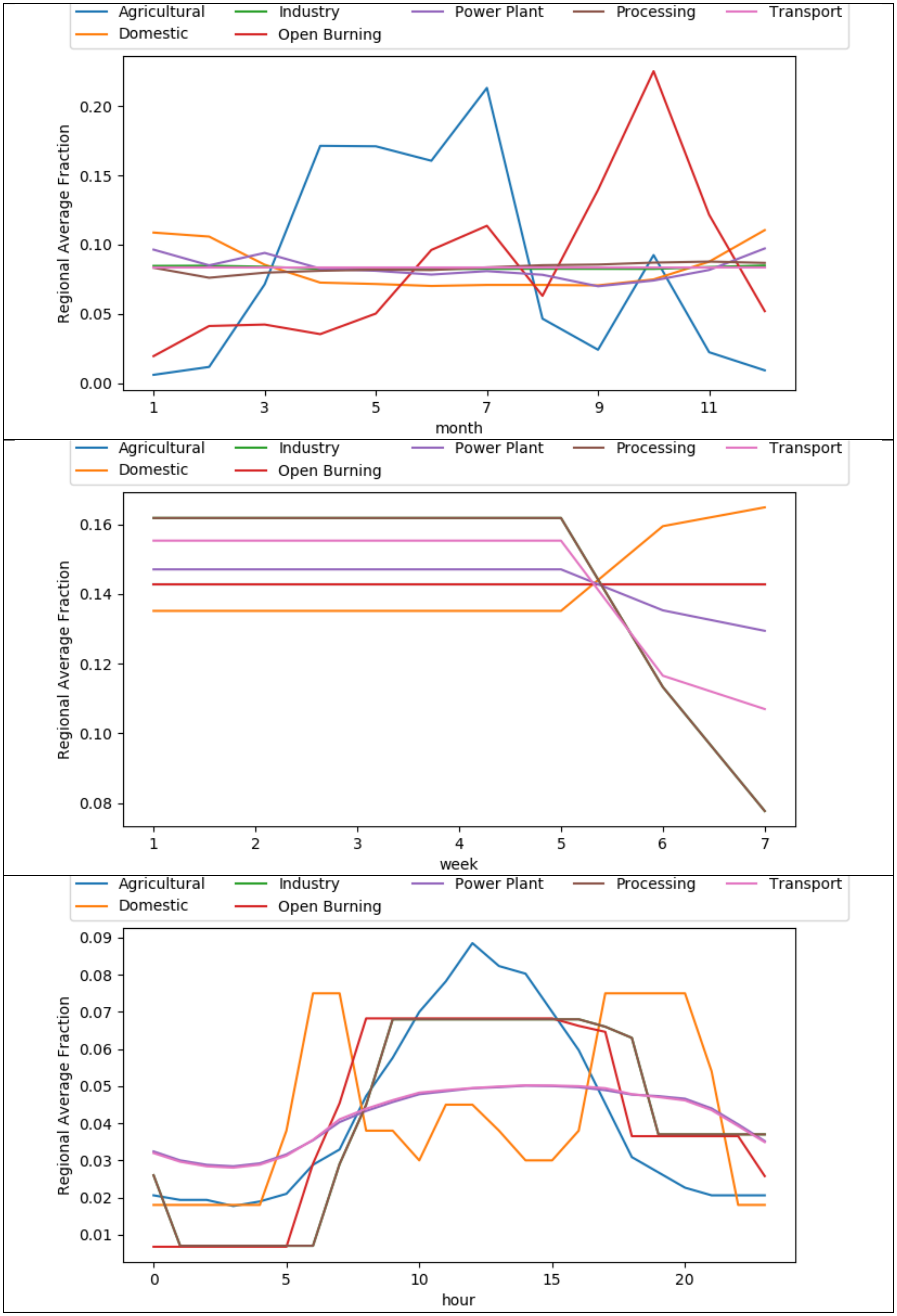
2.2.1 Temporal Allocation

Included in the THU data release were annual emissions files, and temporal profiles on a month-of-year, day-of-week, and hour-of-day basis. Temporal profiles vary by broad sector (AG/agriculture, DO/domestic, IN/industry, PP/power plant, PR/industry process, and TR/transport) and by Chinese province. Because daily temporalization depends only on the day of the week, emissions for seven representative days per month, one for each day of the week, are sufficient.

A province-to-grid cell cross-reference for the China 27km grid was used in combination with the temporal factors. Figure 2-6. shows the averages of province-level monthly, daily, and hourly temporal profiles. These temporal profiles were gridded for each sector and combined to create an annual hour-of-year basis file. Then, the gridded hourly profiles were applied to the annual gridded emissions for each sector to create emissions files with 25 hourly timesteps for each representative day of the year (one file for each day of the week for each month). Application of gridded hourly profiles was applied using a Python utility called apply_fracs.py which multiplies the annual China emissions files by the hourly fraction matrix to generate the representative day, hourly emissions files.

For both 2016 modeling (base year) and 2015 modeling (spinup year), the same set of representative day emissions are used in China.

Figure 2-6. Time allocation factors for the China Inventory. Averages of province-specific allocation factors are shown.



2.2.2 Chemical Speciation

The THU dataset included pre-speciated emissions for VOC and PM2.5 species, but additional processing related to speciation was necessary to prepare these emissions for air quality modeling. The following steps were all performed using the same Python utility (apply_fracs.py) as the temporalization. For VOC species, only a time conversion was necessary; emissions units from the previous step were in moles per hour, which we converted to moles per second for CMAQ modeling. For PM2.5 species, emissions units were in metric tons per hour (not short tons as in most North America emissions inventories), and were converted to grams per second. The THU dataset included emissions for NOX, but not individual species NO or NO2; we split NOX into NO (90%) and NO2 (10%), and also converted from metric tons per hour to moles per second. NH3 and SO2 only required a unit conversion from metric tons per hour to moles per second.

Finally, the THU dataset included PM10 and individual PM2.5 species, but not the PMC species. We added the PMC species to the emissions files by subtracting the sum of PM2.5 from PM10. Occasionally, the sum of PM2.5 emissions slightly exceeded the PM10 value, resulting in a small negative value for PMC. This was most common in the transport sector. In order to prevent errors in emissions processing or air quality modeling, any instance of negative PMC was reset to a value of zero.

2.2.3 Spatial Allocation

The next step to prepate the THU China emissions for air quality modeling is to regrid the emissions from the Lambert 27km grid to the 108km hemispheric grid. For this, the I/O API utility mtxcalc was run to create a conversion matrix from the 27km China grid to the 108km hemispheric grid. Then, a Python script was used to re-project the hourly speciated emissions from the 27km China grid to the 108km hemispheric grid using the conversion matrix from mtxcalc. Early versions of I/O API v3.2 are known to produce incorrect conversion matrices from mtxcalc, but this has been fixed in the latest build of v3.2; I/O API v3.1 is also valid.

2.2.4 Vertical Allocation

Vertical allocation was applied to the hourly, speciated, and gridded emissions, consistent with how the HTAP sectors are processed. China sectors that are mapped to the HTAP industry sector (see Table 2-6) were vertically allocated using the same layer fractions that are used to allocate the g_industry sector. Similarly, the China power plant sector was vertically allocated using the layer fractions from the g_energy sector. All Chinese domestic, transport, and agriculture emissions were retained as single layer, low-level emissions.

Layer fractions were applied using the SMOKE program Layalloc using a similar procedure as for the HTAP sectors g_industry and g_energy. As with the HTAP sectors, because layer heights vary temporally, layered emissions for the China industry and energy sectors are processed for each day of the year, separately for 2016 (base year) and 2015 (spinup year).

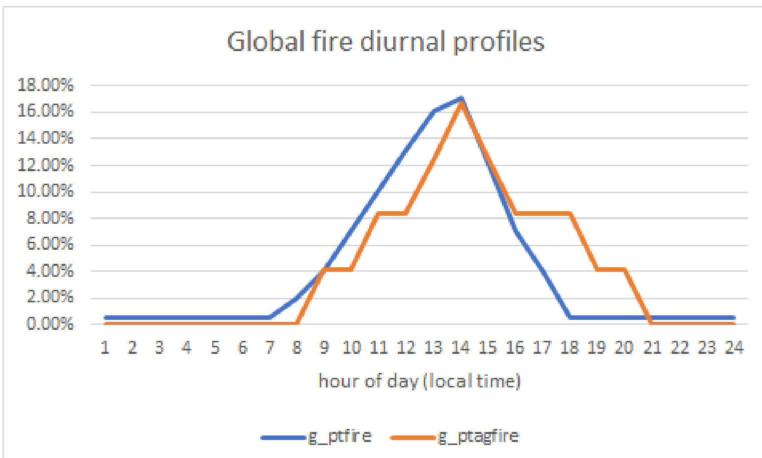
The resulting China emissions files, which include hourly temporalization, full speciation, vertical allocation, and spatial allocation on the hemispheric 108km grid, are read directly by the SMOKE program Mrggrid and merged with the other sectors.

2.3 Global FINN fires (g_ptfire, g_ptagfire)

Annual 2015 and 2016 fire emissions outside of North America were developed from FINN (Fire Inventory from NCAR) v1.5 daily fire emissions. For FINN fires, listed vegetation type codes of 1 and 9 are defined as agricultural burning, all other fire detections and assumed to be wildfires. Wildfires are processed in the g_ptfire sector separately from ag burning in the g_ptagfire sector. All wildland fires that are not defined as agricultural are assumed to be wild fires rather than prescribed. FINN fire detects less than 50 square meters (0.012 acres) are removed from the inventory because they are smaller than the pixel size of the remote sensing data and are therefore assumed to be false detects. Fires in North America, Central America, and the Caribbean were excluded from the g_ptfire and g_ptagfire sectors because fires in these areas are included in North America portion of the hemispheric platform (ptfire, ptagfire, and ptfire_othna sectors). In China, we include fire emissions from the g_ptfire and g_ptagfire sectors and do not include open burning emissions from the THU inventory.

Global fire processing uses a unique set of country codes that are similar to, but not the same as, standard FIPS codes used in North America. The locations of FINN fires are geocoded from latitude and longitude to a country code and a time zone code. The 6-digit FIPS-like codes used for global fires follow the format *9TTCCC*, where TT indicates the time zone (01 through 24), and CCC is the country-level GEOCODE that is used for HTAP sector processing. This allows for the generation of emissions summaries by country, and supports diurnal temporalization of fires in local time. Diurnal profiles for global FINN wild fires and ag fires are shown in Figure 2-7.

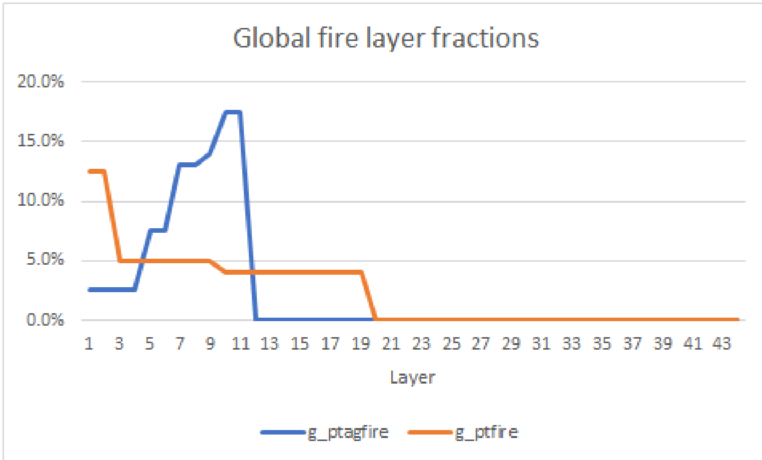
Figure 2-7. Diurnal temporal profiles for global wild fires and ag fires



The FINN fire inventory includes heat content and location information specific to individual fires, which can be used to calculate fire-specific plume rise as is done for North America fires. However, given the large number of fires that may exist around the globe at any given time, processing all global fires individually through the SMOKE model is more computationally intensive than can be accomplished on EPA computing systems in a reasonable amount of time. To reduce the computational complexity, we reduce the number of unique fires in the global wildfire and ag fire datasets. After fires are geocoded to time zone and country, latitude and longitude coordinates for each fire are rounded to the nearest tenth of a degree (0.1°). Then, all fires that share the same time zone, country code, and rounded coordinates, are summed to a single inventory source. This reduces the size of the annual fire inventory by a factor of approximately 15, and the size of the daily fire inventory by a factor of approximately 10. While this does reduce the spatial accuracy of the inventory, this new resolution is equivalent to the resolution of gridded HTAP emissions inventories and is still more than 10 times more precise than the resolution of the 108km hemispheric modeling domain, and so the impact of coordinate rounding on 108km air quality modeling is minimal.

When summing fire sources that share a common time zone, country code, and rounded coordinates, we lose the fire-specific heat content information that is needed to calculate plume rise. So for the g_ptfire and g_ptagfire sectors, we apply sector-wide layer fractions with the SMOKE program Layalloc, similar to how HTAP and THU China sectors are layered. Different layer fractions are applied to g_ptfire and g_ptagfire; this is the main reason wild fires and ag fires are processed separately. The layer fractions for the two global fire sectors are shown in Figure 2-8.

Figure 2-8. Layer fractions for global wild fires (g_ptfire) and ag fires (g_ptagfire)



Annual emissions totals for the g_ptfire and g_ptagfire sectors are in Table 2-8.

Table 2-8. Emissions totals for global fire sectors, 108km hemispheric domain, year 2016, tons/year

Sector	**CO**	**NH3**	**NOX**	**PM10**	**PM2.5**	**SO2**	**VOC**
g_ptfire	121,285,767	2,005,131	6,058,488	21,767,734	13,499,258	780,250	34,654,568
g_ptagfire	25,959,983	382,301	1,576,886	2,362,013	1,847,549	150,067	9,932,375

2.4 Other global emissions

In addition to emissions from the North America regional modeling platform, HTAP, THU (China), and global fires from FINN, the hemispheric modeling platform also includes biogenic emissions, lightning NOx emissions, and ocean chlorine emissions.

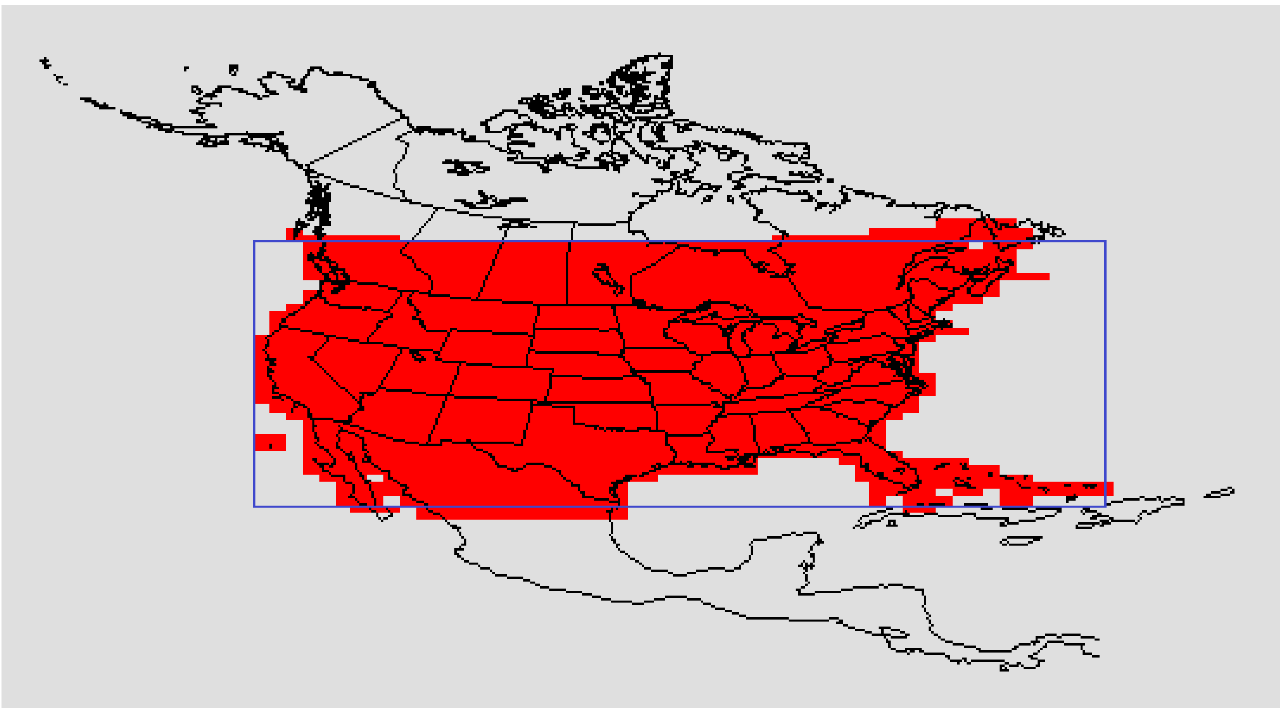
2.4.1 Biogenic emissions

Biogenic emissions for the 108km hemispheric modeling domain consist of two components: emissions from the Biogenic Emission Inventory System (BEIS) version 3.61 in and near the United States, and emissions from the Model of Emissions of Gases and Aerosols from Nature (MEGAN) elsewhere in the domain. BEIS emissions from 12km regional modeling were elected for the region surrounding the United States to be as consistent with the regional modeling platform as possible. However, the BEIS model cannot be used globally because the land use data upon which BEIS relies, specifically the BELD dataset, does not extend beyond North America. Therefore, we use biogenics from the MEGAN model to fill in the rest of the hemispheric domain.

BEIS 3.61 was run using SMOKE for the 12US1 regional modeling domain. The gridded emissions from 12US1 were then spatially allocated to the 108km hemispheric domain using a Python re-gridding utility.

Figure 2-9 shows the spatial extent of 12US1 BEIS emissions on the 108km hemispheric domain. This is a plot of emissions on the hemispheric domain, zoomed in on North America; the red region represents nonzero emissions from 12US1 BEIS. To simplify the process of preventing double-counted emissions along the edges of the red area in Figure 9, rather than identify each individual cell as either a "BEIS" cell or a "MEGAN" cell, we identified a rectangular region which has 100% 12US1 BEIS coverage – specifically, (73,31) to (124,64), as shown in blue on Figure 2-9. For BEIS, we keep all emissions inside the blue rectangle and zero out all emissions outside the blue rectangle. Conversely, for MEGAN, we keep all emissions outside the blue rectangle and zero out all emissions inside the blue rectangle. All zero-outs were performed using a Python-based netCDF utility. Sector names for these two sectors are "beis" for the BEIS component and "g_biog" (global biogenics) for the MEGAN component.

Figure 2-9. Spatial extent of 12US1 BEIS emissions on the 108km hemispheric domain



Biogenic emissions from the MEGAN model were processed for a 2° x 2.5° global GEOS-Chem domain. The MEGAN emissions were reallocated to the 108km hemispheric domain. Model output mass flux emissions values were converted to emissions rates using the area of each grid cell. Gas phase species values were then converted from mass rates to mole emissions rates. Volatile organic species were combined to match the CB6 species needed for CMAQ. To avoid the double counting of biogenic emissions, the region in the blue rectangle zeroed out as described above. Biogenic emissions from MEGAN are processed for a single representative day per month for both 2015 and 2016. Formaldehyde emissions from MEGAN were lower than expected compared to alternative datasets, and so FORM emissions were increased by 70% compared to MEGAN outputs.

Both BEIS and MEGAN include NOx emissions from soil. The total Co, NO and VOC emissions are shown in Table 2-9.

Table 2-9. Annual biogenic emissions totals, 108km hemispheric domain, year 2016, tons/year

Sector	CO	NO	VOC[1]
beis (US + vicinity)	9,956,463	1,961,185	58,179,072
megan (rest of domain)	34,386,775	16,252,008	260,825,447

[1] *VOC emissions are approximated using a sum of individual VOC species.*

2.4.2 Lightning NOx emissions

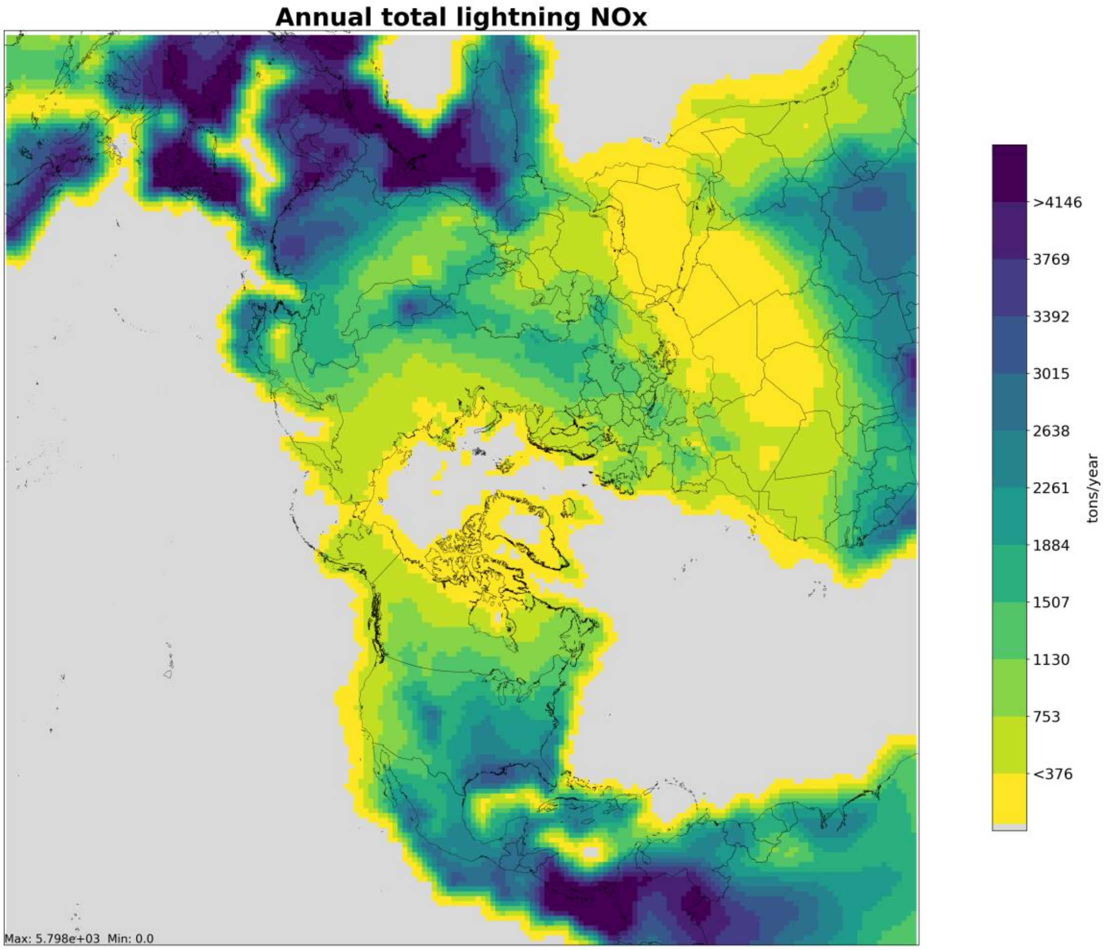
NOx emissions from lightning strikes, known as Lightning NOx, were developed. Monthly lightning NOx emissions including vertical allocation for all 44 layers were created from a global inventory (Price, 1997). Lightning NOx was speciated to model species NO and NO2 using a standard 90/10 split.

Diurnal temporalization for lightning NOx was applied using lightning strike flash rate data from Blakeslee, et al., 2014 (http://www.sciencedirect.com/science/article/pii/S0169809512003250#t0010). This lightning data includes diurnal variation in lightning strikes in UTC by season (summer, fall, winter, spring) and by continent. Diurnal temporal profiles were calculated from this data for each season and continent and then applied to the monthly total lightning NOx emissions, using the GRIDMASK file to map cells to continents. Lightning strikes over open water use a flat diurnal profile.

There is no day-of-month temporalization, and so there is a single hourly lightning NOx emissions file for each month. The same lightning NOx emissions are used for both 2015 (spinup year) and 2016 (base year).

Figure 2-10 shows a plot of lightning NOx annual emissions for the 108km hemispheric domain. There are approximately 30 million tons per year of lightning NOx emissions.

Figure 2-10. Lightning NOx Annual emissions



2.4.3 Ocean chlorine emissions

The ocean chlorine gas emission estimates are based on the build-up of molecular chlorine (Cl2) concentrations in oceanic air masses (Bullock and Brehme, 2002). Ocean chlorine emissions for the 108km hemispheric domain were processed using an ocean mask file for the hemispheric domain, representing the amount of salt water coverage in each grid cell in the domain.

2.5 Changes to North America sectors to support hemispheric modeling

Documentation regarding emissions from the United States, Canada, and Mexico, is available in the 2016 alpha regional platform TSD. This section covers differences between the regional platform and the hemispheric platform concerning emissions in North America.

2.5.1 Emissions inventory differences

As discussed in the next section, hemispheric emissions in the onroad and afdust_adj sectors were reallocated from 12US1 to the 108km hemispheric domain. Therefore, those two sectors exclude emissions in Alaska, Hawaii, Puerto Rico, and Virgin Islands, collectively referred to as AK/HI/PR/VI. In order to include AK/HI/PR/VI onroad and afdust emissions in the hemispheric modeling platform without rerunning the onroad or afdust emissions for the entire U.S., the AK/HI/PR/VI onroad inventory from

2014NEIv2 was included in the onroad_can (Canada onroad) sector, and the AK/HI/PR/VI afdust inventory from 2014NEIv2 was included in the othafdust (Canada afdust) sector.

In the regional modeling platform, the cmv_c3 sector includes emissions in U.S. state waters, U.S. federal waters, and "non-US" emissions beyond federal waters. In the hemispheric modeling platform, the cmv_c3 sector includes emissions in U.S. state and federal waters, but does not include non-US emissions beyond federal waters. As discussed in the HTAP section of this document, non-US C3 emissions are excluded from the hemispheric cmv_c3 sector to prevent a double count with emissions from the HTAP ships sector.

Biogenics, as discussed in Section 2.4.1, are based on a combination of the BEIS and MEGAN models in the hemispheric platform, compared to the regional platform which only uses BEIS.

Otherwise, the 2016 hemispheric modeling platform uses the same North America emissions inventories as the 2016 alpha regional modeling platform.

2.5.2 Spatial Allocation

For most North America sectors, emissions were processed for the 108km hemispheric domain in SMOKE using spatial surrogates for the hemispheric domain. For some North America sectors, emissions were processed for the 12US1 regional modeling domain and then reallocated to the 108km hemispheric domain, in order to ensure consistency between regional modeling and hemispheric modeling for sectors that are sensitive to meteorology or other grid-specific inputs. Table 2-10 specifies the approach for all North America emissions sectors.

Table 2-10. Hemispheric spatial allocation approach for all North America sectors

Platform Sector	Spatial allocation approach
afdust_adj	Regridded from 12US1; excludes AK/HI/PR/VI
onroad	Regridded from 12US1; excludes AK/HI/PR/VI
onroad_ca_adj	Regridded from 12US1
ag	Processed with 108km surrogates; temporalization based on 12US1 meteorology
cmv_c1c2	Processed with 108km surrogates
cmv_c3	Point sources allocated to 108km grid; excludes non-US C3
nonpt	Processed with 108km surrogates
nonroad	Processed with 108km surrogates
np_oilgas	Processed with 108km surrogates
rail	Processed with 108km surrogates
rwc	Processed with 108km surrogates; temporalization based on 12US1 meteorology
othafdust	Processed with 108km surrogates and adjusted with 108km meteorology; includes AK/HI/PR/VI
onroad_can	Processed with 108km surrogates; includes AK/HI/PR/VI
onroad_mex	Processed with 108km surrogates
othar	Processed with 108km surrogates
othpt	Point sources allocated to 108km grid
ptagfire	Point sources allocated to 108km grid
ptegu	Point sources allocated to 108km grid
ptnonipm	Point sources allocated to 108km grid
pt_oilgas	Point sources allocated to 108km grid
Ptfire	Point sources allocated to 108km grid
ptfire_othna	Point sources allocated to 108km grid
Beis	Regridded from 12US1 and zeroed out outside of (73,31) to (124,64); see Section 2.4.1

2.5.3 Vertical Allocation

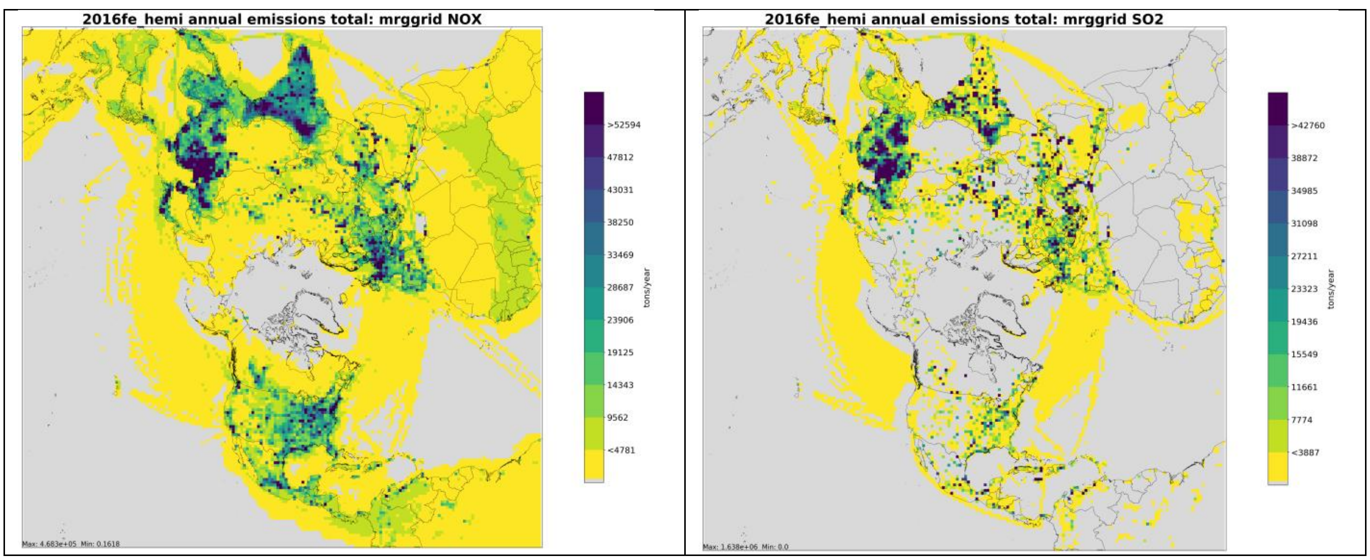
For regional modeling, point source emissions are processed as "inline" point sources, and plume rise is calculated not within SMOKE, but within CMAQ. Inline CMAQ point source layering requires stack information for individual point sources. Because the gridded HTAP inventories do not have stack information from which plume rise can be calculated within CMAQ, we must process layering and create 3-D layered emissions in SMOKE for all sectors, including North America sectors for which we do have stack parameters.

For North America sectors, plume rise is calculated using the SMOKE program Laypoint, which uses heat content for fires and stack parameters for other point sources to estimate plume rise on a source-by-source basis. This is for the following sectors: cmv_c3, othpt, ptegu, ptnonipm, pt_oilgas, ptagfire, ptfire, and ptfire_othna.

2.6 Final CMAQ-Ready Hemispheric Emissions

The first two sections of this technical support document has highlighted the various inventory and ancillary datasets that were used to generate CMAQ-ready emissions for modeling air quality for the Northern Hemispheric modeling domain.   Annual NOx and SO2 emissions are shown in Figure 2-11. These annual emissions can be used to compare versus the various sensitivity CMAQ runs discussed in next section.

Figure 2-11. Annual NOx(left) and SO2(right) emissions for base case run.



3 Sensitivity Runs

In addition to the "base case" modeling, CMAQ modeling was performed for several sensitivity cases. Most of the sensitivity cases involve zero outs to emissions in a particular region, or a particular category of emissions, or a combination. For each sensitivity case, we processed new emissions for both year 2015 and year 2016. The following sensitivity cases were processed:

- **ZANTH**: Zero out all anthropogenic emissions in the entire domain.
- **ZROW**: Zero out all anthropogenic emissions outside the United States.
- **ZUSA**: Zero out all anthropogenic emissions inside the United States.
- **ZSHIP**: Zero out all CMV C3 emissions in the entire domain.
- **ZCHN**: Zero out all anthropogenic emissions in China.
- **ZIND**: Zero out all anthropogenic emissions in India.
- **ZCANMEX**: Zero out all anthropogenic emissions in Canada and Mexico.
- **ZFIRE**: Zero out all fire emissions in the entire domain.
- **EdgarCHN**: Use HTAPv2 emissions in China instead of the THU China dataset.

The specifications for each sector in each sensitivity run are summarized in Table 3-1, with additional detail in Section 3.1.

Table 3-1. Hemispheric sensitivity run sector table summary

Sector	Includes	ZANTH	ZROW	ZUSA	ZSHIP	ZCHN	ZIND	ZCANMEX	ZFIRE	EdgarCHN
afdust_adj	Continental U.S.	zero out	include	zero out	include	include	include	include	include	include
ag	U.S.	zero out	include	zero out	include	include	include	include	include	include
cmv_c1c2	U.S. state+federal waters	zero out	include	zero out	include	include	include	include	include	include
cmv_c3	U.S. state+federal waters	zero out	include	zero out	zero out	include	include	include	include	include
nonpt	U.S.	zero out	include	zero out	include	include	include	include	include	include
nonroad	U.S.	zero out	include	zero out	include	include	include	include	include	include
np_oilgas	U.S.	zero out	include	zero out	include	include	include	include	include	include
onroad	Continental U.S. except California	zero out	include	zero out	include	include	include	include	include	include
onroad_ca_adj	California	zero out	include	zero out	include	include	include	include	include	include
pt_oilgas	U.S.	zero out	include	zero out	include	include	include	include	include	include
ptagfire	U.S.	zero out	include	zero out	include	include	include	include	zero out	include
ptegu	U.S.	zero out	include	zero out	include	include	include	include	include	include
ptnonipm	U.S.	zero out	include	zero out	include	include	include	include	include	include
rail	U.S.	zero out	include	zero out	include	include	include	include	include	include
rwc	U.S.	zero out	include	zero out	include	include	include	include	include	include
onroad_can	Canada + AK/HI/PR/VI	zero out	zero out Canada	zero out AK, HI, PR, VI	include	include	include	zero out Canada	include	include
onroad_mex	Mexico	zero out	zero out	Include	include	include	include	zero out	include	include
othafdust	Canada + AK/HI/PR/VI	zero out	zero out Canada	zero out AK, HI, PR, VI	include	include	include	zero out Canada	include	include
othar	Canada + Mexico	zero out	zero out	include	zero out Canada C3 CMV	include	include	zero out	include	include
othpt	Canada + Mexico	zero out	zero out	include	include	include	include	zero out	include	include
ptfire	U.S.	zero out prescribed fires	include	zero out prescribed fires	include	include	include	include	zero out	include
ptfire_othna	Canada, Mexico, Central America, Caribbean	zero out prescribed fires	zero out prescribed fires	include	include	include	include	zero out prescribed fires	zero out	include
g_ptfire	Outside North America	include	include	include	include	include	include	include	zero out	include

Sector	Includes	ZANTH	ZROW	ZUSA	ZSHIP	ZCHN	ZIND	ZCANMEX	ZFIRE	EdgarCHN
g_ptagfire	Outside North America	zero out	zero out	include	include	zero out China	zero out India	include	zero out	include
g_ag	Outside US/CAN/MEX/China	zero out	zero out	include	include	include	zero out India	include	include	rerun with China included
g_air_cds	Entire domain	zero out	zero out all except US	zero out US	include	zero out China	zero out India	zero out Canada, Mexico	include	include
g_air_crs	Entire domain	zero out	zero out all except US	zero out US	include	zero out China	zero out India	zero out Canada, Mexico	include	include
g_air_lto	Outside US/CAN	zero out	zero out	include	include	zero out China	zero out India	zero out Mexico	include	include
g_energy	Outside US/CAN/MEX/China (includes CO in China)	zero out	zero out	include	include	zero out China CO	zero out India	include	include	rerun with China included
g_industry	Outside US/CAN/MEX/China (includes CO in China)	zero out	zero out	include	include	zero out China CO	zero out India	include	include	rerun with China included
g_residential	Outside US/CAN/MEX/China (includes CO in China)	zero out	zero out	include	include	zero out China CO	zero out India	include	include	rerun with China included
g_ships	Outside US Federal Waters	zero out	zero out	include	zero out	zero out China	zero out India	include	include	include
g_transport	Outside US/CAN/MEX/China (includes CO in China)	zero out	zero out	include	include	zero out China CO	zero out India	include	include	rerun with China included
all THU China	China	zero out	zero out	include	include	zero out	include	include	include	zero out
beis	Continental U.S. and vicinity	include	include	include	include	include	include	include	include	include
g_biog	Entire domain except Continental U.S. vicinity	include	include	include	include	include	include	include	include	include
lightning	Entire domain	include	include	include	include	include	include	include	include	include
ocean_cl2	Entire domain	include	include	include	include	include	include	include	include	include

3.1 Sensitivity Run Specifications

Zero-out sensitivity cases are processed by excluding emissions sectors from the final sector merge, reprocessing sectors with a partial zero-out, and reusing remaining sectors from the base run, or from other previously completed sensitivity runs.

3.1.1 ZANTH

The ZANTH run excludes all anthropogenic emissions in the entire hemispheric modeling domain, in order to isolate the impact of non-anthropogenic emissions on air quality modeling results. This means almost all sectors from the base case are excluded from the ZANTH case. The only emissions *included* in the ZANTH run are:

- Biogenics (beis and g_biog sectors)
- Lightning NOx
- Ocean chlorine
- Wildfires from the ptfire, ptfire_othna, and g_ptfire sectors

For the purposes of the ZANTH and other sensitivity cases concerning anthropogenic emissions, prescribed fires and ag fires are considered anthropogenic, while wildfires are considered non-anthropogenic.

U.S. fires are represented in two sectors: ptfire, which includes wildfires and prescribed fires (labeled with different SCCs), and ptagfire, which includes ag fires. For the ZANTH run, we exclude the ptagfire sector, and reprocess the ptfire sector with all prescribed fire emissions removed from the inventory. Table 3-2 shows the fraction of emissions from wildfires and prescribed burns in 2016.

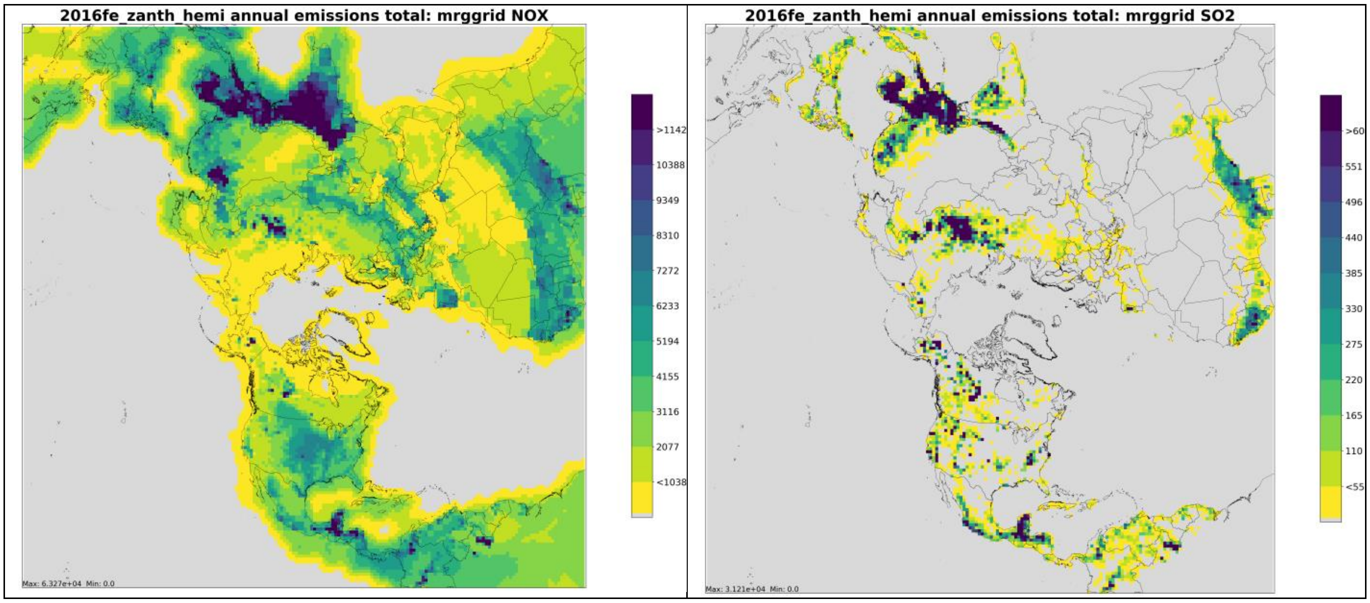
Table 3-2. Fraction of 2016 emissions from wildfire and prescribed burns in USA

Pollutant	Wild	Prescribed
CO	60.10%	39.90%
NH3	59.90%	40.10%
NOX	49.20%	50.80%
PM10	58.90%	41.10%
PM2_5	58.90%	41.40%
SO2	54.50%	45.50%
VOC	59.90%	40.10%

Other North America fires are in the ptfire_othna sector, which includes both wildfires and ag fires. The ptfire_othna inventories do not have prescribed fires broken out separately; that is, all fires that are not ag fires share the same SCC. Therefore, all ptfire_othna fires that are not ag fires are considered to be wildfires and are included in ZANTH. For the ZANTH run, we reprocess the ptfire_othna sector with all ag fire emissions removed from the inventory.

Fires outside of North America are in the g_ptfire (wildfires) and g_ptagfire (ag fires) sectors. Like in the ptfire_othna sector, the g_ptfire inventories do not have prescribed fires broken out separately, and so 100% of the g_ptfire sector emissions are included in the ZANTH run. The g_ptagfire sector is excluded from ZANTH.

Figure 3-1. **Annual NOx(left) and SO2(right) emissions for ZANTH sensitivity run.**



3.1.2 ZROW

The ZROW run excludes all anthropogenic emissions outside the United States, in order to isolate the impact of all non-U.S. emissions on air quality modeling results. “ROW” is an acronym which means “Rest Of World”. The ZROW run includes:

- Everything that is included in ZANTH
- All U.S. anthropogenic sectors from the base case
- The AK/HI/PR/VI portion of onroad_can and othafdust_adj
- HTAP aircraft sector emissions within the United States

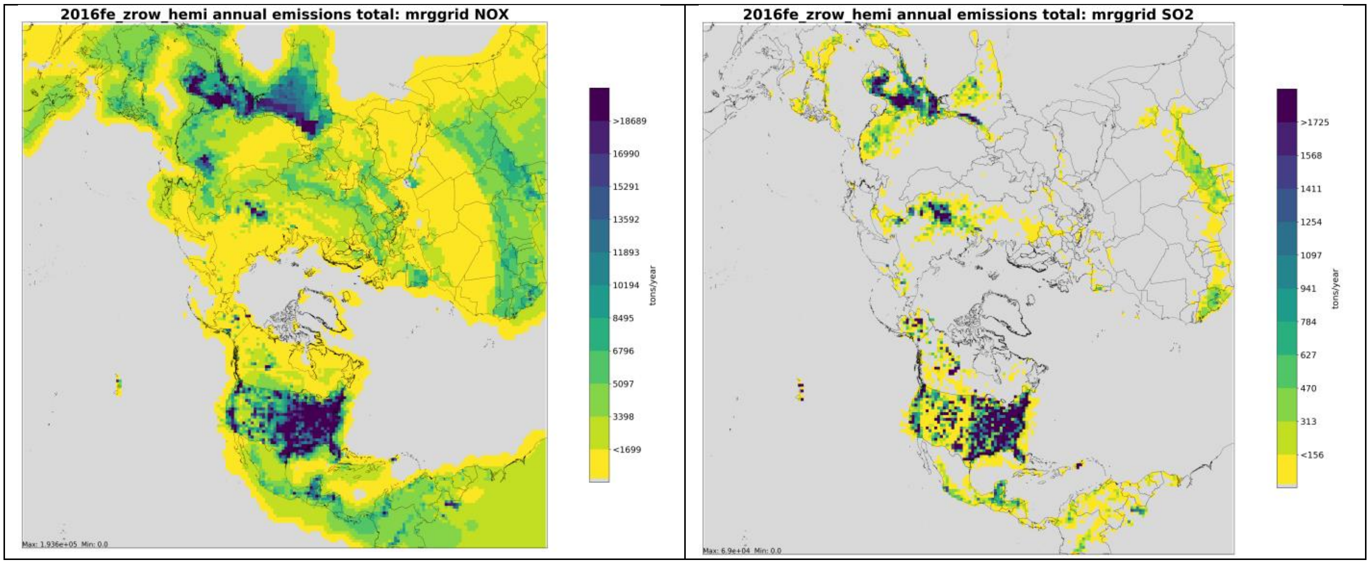
For fire sectors, the ZROW case includes the full ptfire and ptagfire sectors (all U.S. fires, including prescribed and ag); reuses the ptfire_othna emissions from the ZANTH run (with ag fires removed but wildfires retained); and includes 100% of g_ptfire from the base run and none of g_ptagfire (same as ZANTH).

All U.S. sector emissions from the base case are included in full in ZROW. In the base case, the othafdust and onroad_can sectors include a combination of Canada emissions and emissions from Alaska, Hawaii, Puerto Rico and Virgin Islands; for ZROW, these sectors were reprocessed so that they include AK/HI/PR/VI only and do not include any Canadian emissions. All sectors which only include anthropogenic emissions in Canada and Mexico were excluded from ZROW.

Offshore CMV emissions within U.S. federal waters are considered to be United States emissions for the purposes of these sensitivities. Therefore, ZROW includes the 100% of the emissions from the cmv_c1c2 and cmv_c3 sectors, and does not include any emissions from the g_ships sector.

All HTAP sector emissions are excluded from ZROW, with the exception of the g_air_cds and g_air_crs sectors. The CDS and CRS aircraft sectors are the only HTAP sectors which include emissions within the United States, or in this case, United States airspace. For ZROW, the g_air_cds and g_air_crs sectors were reprocessed with all emissions outside the boundaries of the United States zeroed out. For aircraft emissions, only emissions over land areas of the United States are retained; this includes Alaska, Hawaii, and PR/VI. The g_air_lto sector from the base case does not include any United States emissions, since they would have double counted emissions from the North America inventories; therefore, we can exclude g_air_lto from ZROW entirely.

Figure 3-2. Annual NOx(left) and SO2(right) emissions for ZROW sensitivity run.



3.1.3 ZUSA

The ZUSA run excludes all anthropogenic emissions inside the United States, in order to isolate the impact of U.S. emissions on air quality modeling results. ZUSA includes:

- Everything that is included in ZANTH
- All anthropogenic sectors from the base case *except* those from U.S. sectors
- The Canada portion of onroad_can and othafdust_adj
- HTAP aircraft sector emissions outside the United States

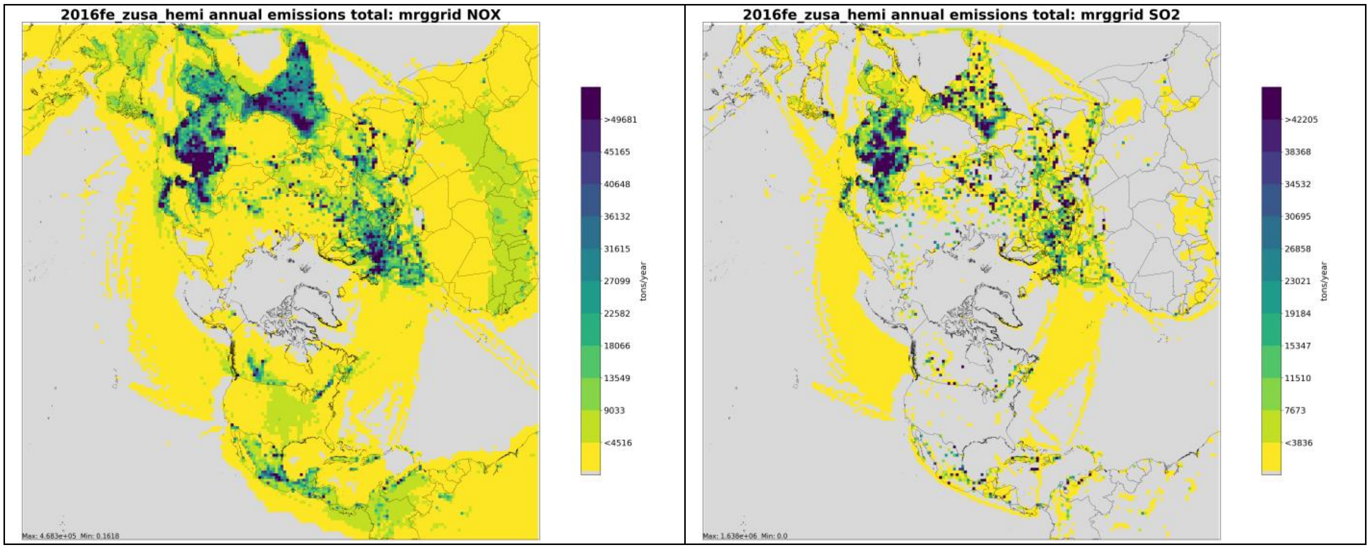
For fire sectors, the ZUSA case includes the full ptfire_othna, g_ptfire, and g_ptagfire sector emissions from the base case (all non-U.S. fires, including ag); reuses the ptfire emissions from the ZANTH run (with prescribed fires removed but wildfires retained); and excludes the ptagfire sector.

All sector emissions from the base case with no U.S. component are included in full in ZROW. In the base case, the othafdust and onroad_can sectors include a combination of Canada emissions and emissions from Alaska, Hawaii, Puerto Rico and Virgin Islands; for ZUSA, these sectors were reprocessed so that they include Canada only and do not include AK/HI/PR/VI only. All sectors which only include anthropogenic emissions in Canada and Mexico were included in full in ZUSA.

Offshore CMV emissions within U.S. federal waters are considered to be United States emissions for the purposes of these sensitivities. Therefore, ZUSA excludes the entirety of the cmv_c1c2 and cmv_c3 sectors, and includes 100% of emissions from the g_ships sector.

All HTAP sector emissions from the base case are included in full in ZUSA, with the exception of the g_air_cds and g_air_crs sectors. The CDS and CRS aircraft sectors are the only HTAP sectors which include emissions within the United States, or in this case, United States airspace. For ZUSA, the g_air_cds and g_air_crs sectors were reprocessed with all emissions inside the boundaries of the United States zeroed out. For aircraft emissions, only emissions over land areas of the United States, including AK/HI/PR/VI, are excluded. The g_air_lto sector from the base case does not include any United States emissions, since they would have double counted emissions from the North America inventories; therefore, we can include 100% of the g_air_lto sector in ZUSA.

Figure 3-3. Annual NOx(left) and SO2(right) emissions for ZUSA sensitivity run.

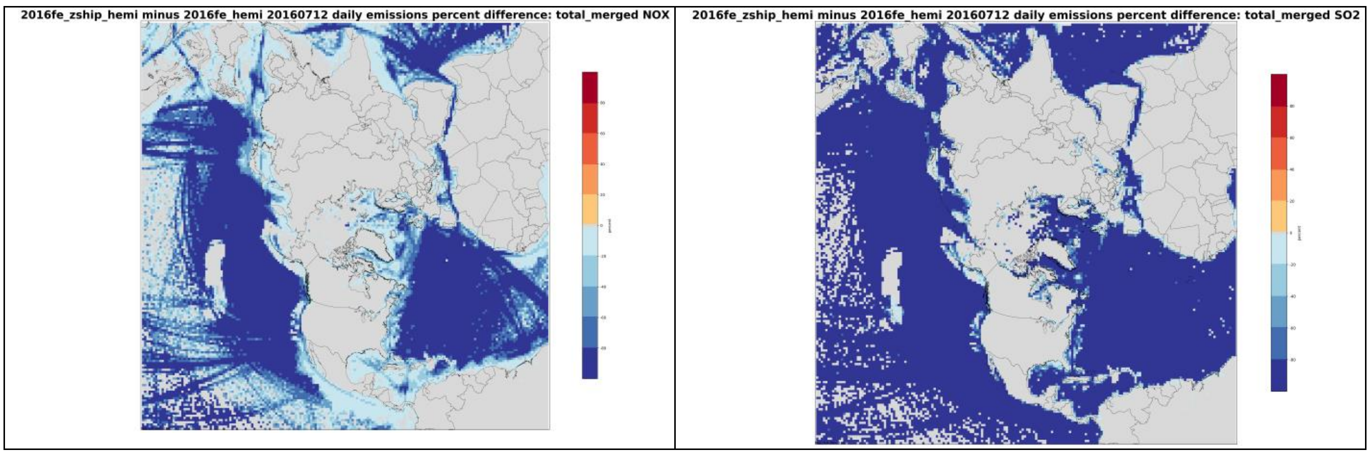


3.1.4 ZSHIP

In the ZSHIP sensitivity run, we exclude all emissions from CMV Category 3 (C3) emissions for the entire domain, in order to isolate the impact of shipping emissions on model results.

The only differences between ZSHIP and the base case concern the cmv_c3, othar, and g_ships sectors. In the United States, ZSHIP includes 100% of the cmv_c1c2 sector but excludes the cmv_c3 sector. In Canada, C3 emissions are included in the othar sector, and so we reprocess the othar sector for ZSHIP with Canada C3 sources removed from the inventory. For the rest of the domain, because we cannot isolate C3 ships from other types of ships in the HTAP shipping sector, we exclude 100% of the g_ships sector emissions from ZSHIP.

Figure 3-4. Percent difference from basecase NOx(left) and SO2(right) weekday-summer emissions for ZSHIP sensitivity run.



3.1.5 ZCHN

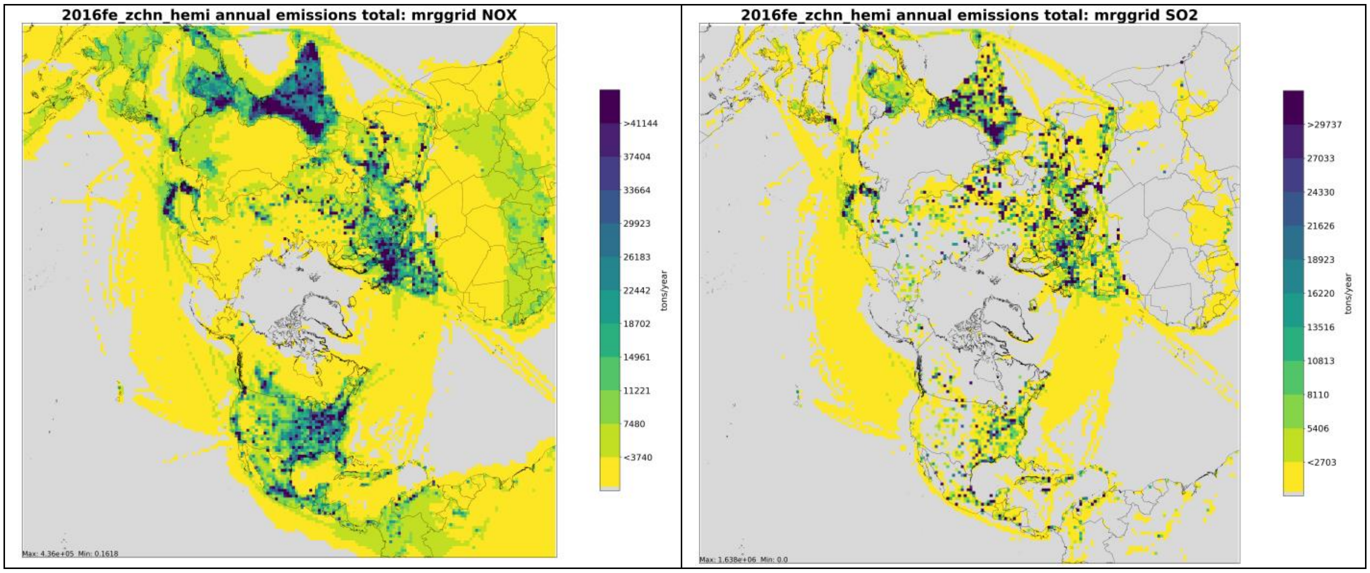
The ZCHN run excludes all anthropogenic emissions inside China, in order to isolate the impact of China emissions on air quality modeling results. All emissions in ZCHN are the same as in the base case, except for the HTAP, THU China, and global FINN fire sectors.

Recall that emissions sectors based on HTAP inventories, such as g_residential and g_transport, include carbon monoxide emissions in China, since the THU China dataset does not include CO emissions. Therefore, it was necessary to reprocess all HTAP sectors for ZCHN, where instead of retaining CO emissions in China, we zero out emissions for all pollutants in China. Emissions were zeroed out in both China land areas and along the China coastline, as defined by the extent of the THU China dataset (see Section 2.2). Aircraft emissions over China were zeroed out from the g_air_cds, g_air_crs, and g_air_lto sectors. Emissions in Taiwan were not zeroed out in ZCHN.

All emissions from the THU China dataset are excluded from ZCHN for all sectors.

For fire sectors, emissions in the g_ptfire sector are retained in full, since that sector's emissions are treated as wildfires and as non-anthropogenic. We reprocessed the g_ptagfire sector for ZCHN with all fires that have a China GEOCODE removed from the inventory.

Figure 3-5. Annual NOx(left) and SO2(right) emissions for ZCHN sensitivity run.



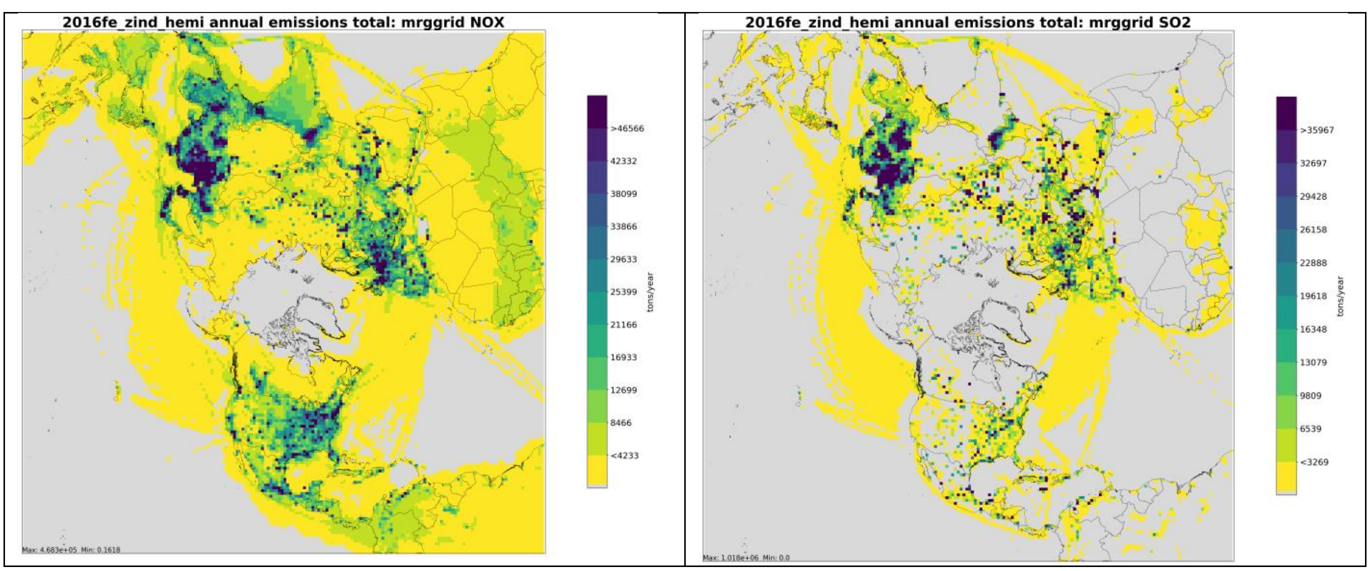
3.1.6 ZIND

The ZIND run excludes all anthropogenic emissions inside India, in order to isolate the impact of India emissions on air quality modeling results. All emissions in ZIND are the same as in the base case, except for the HTAP and global FINN fire sectors.

For ZIND, we reprocess all HTAP sectors with all emissions in India, according to the India GEOCODE, zeroed out. This includes aircraft emissions as well as other types of emissions in the HTAP dataset.

For fire sectors, emissions in the g_ptfire sector are retained in full, since that sector's emissions are treated as wildfires and as non-anthropogenic. We reprocess the g_ptagfire sector for ZIND with all fires that have an India GEOCODE removed from the inventory.

Figure 3-6. Annual NOx(left) and SO2(right) emissions for ZIND sensitivity run.



3.1.7 ZCANMEX

The ZCANMEX run excludes all anthropogenic emissions inside Canada and Mexico, in order to isolate the impact of Canadian and Mexican emissions on air quality modeling results. ZCANMEX includes:

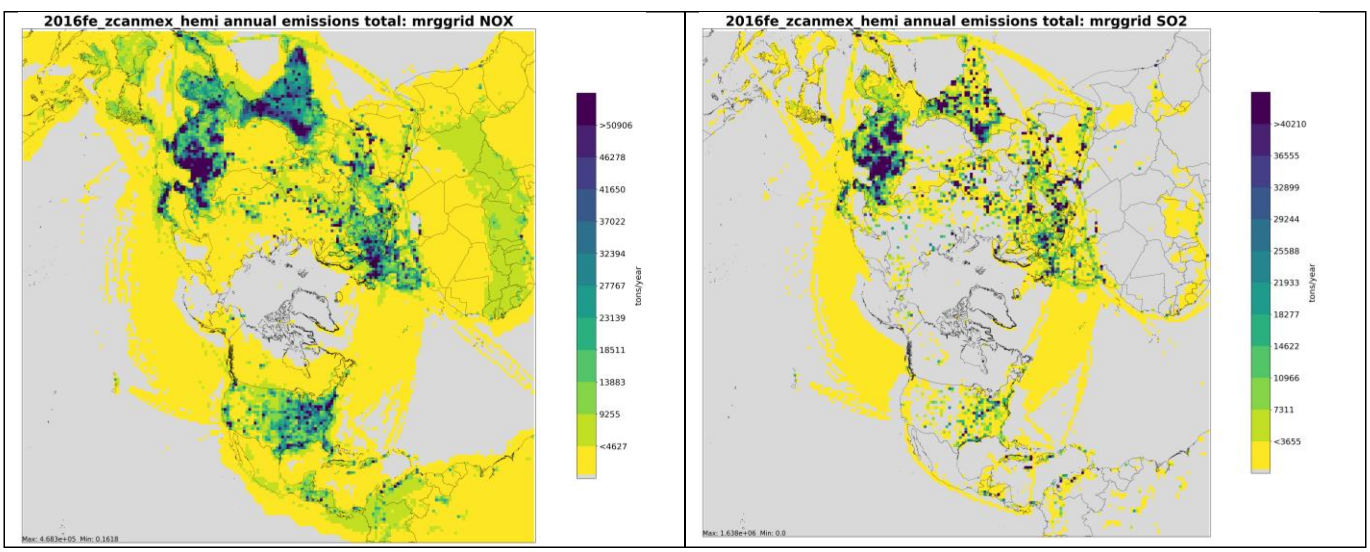
- Everything that is included in ZANTH
- All anthropogenic sectors from the base case *except* those from Canada and Mexico sectors
- The AK/HI/PR/VI portion of onroad_can and othafdust_adj
- HTAP aircraft sector emissions outside Canada and Mexico

For fire sectors, the ZCANMEX case includes the full ptfire, ptagfire, g_ptfire, and g_ptagfire sector emissions from the base case. For the ptfire_othna sector, we reprocess the emissions with all Canada and Mexico ag fires removed, but we retain all Canada and Mexico wildfires. The ZCANMEX ptfire_othna sector is equivalent to the ZANTH ptfire_othna sector, except that ZCANMEX ptfire_othna includes ag fires in Central America and the Caribbean, whereas ZANTH ptfire_othna does not include any ag fires.

All sector emissions from the base case with no Canada or Mexico component are included in full in ZROW. In the base case, the othafdust and onroad_can sectors include a combination of Canada emissions and emissions from Alaska, Hawaii, Puerto Rico and Virgin Islands. For ZCANMEX, we reuse othafdust_adj and onroad_can emissions from the ZROW run, which include AK/HI/PR/VI only and do not include Canada. All sectors which only include anthropogenic emissions in Canada and Mexico were excluded from ZCANMEX.

All HTAP sector emissions from the base case are included in full in ZCANMEX, with the exception of the g_air_cds, g_air_crs, and g_air_lto sectors. The aircraft sectors are the only HTAP sectors which include emissions within Canada or Mexico. For ZCANMEX, the three HTAP aircraft sectors were reprocessed with all emissions inside the boundaries of Canada and Mexico zeroed out. Note that in the base case, Canada emissions were already removed from g_air_lto to prevent a double count with the Canadian aircraft inventory, but Mexico was not already removed from g_air_lto.

Figure 3-7. Annual NOx(left) and SO2(right) emissions for ZCANMEX sensitivity run.

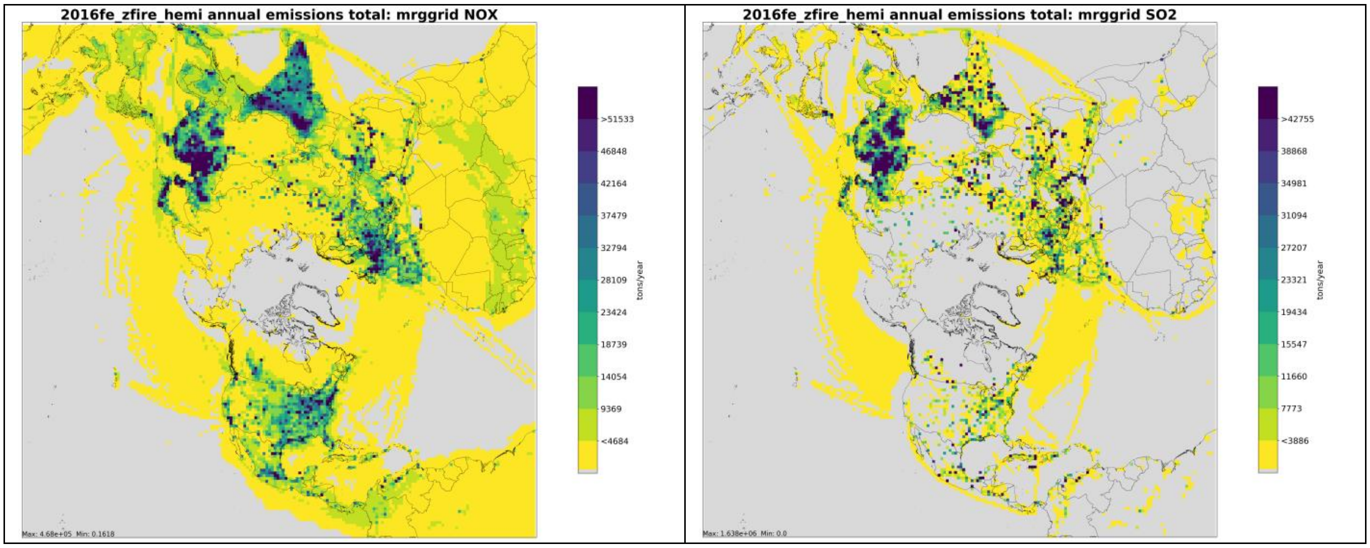


3.1.8 ZFIRE

In the ZFIRE sensitivity simulation, all fire emissions in the entire domain are excluded, in order to isolate the impact of fire emissions in air quality model results. Wildfires, prescribed fires, and ag fires are all excluded from ZFIRE.

All emissions from the base case are included in ZFIRE, except for the ptfire, ptagfire, ptfire_othna, g_ptfire, and g_ptagfire sectors, each of which is excluded from ZFIRE.

Figure 3-8. Annual NOx(left) and SO2(right) emissions for ZFIRE sensitivity run.



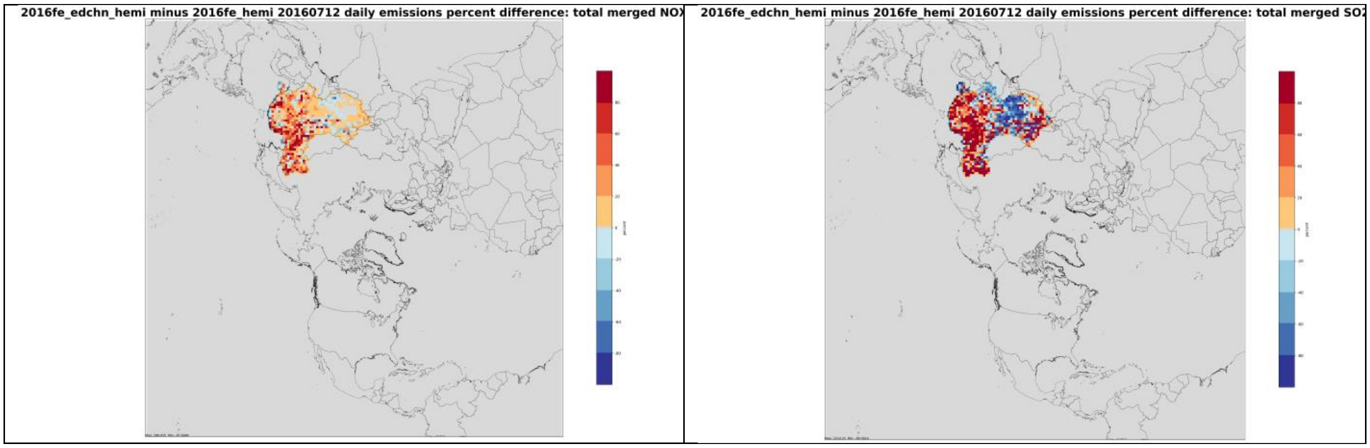
3.1.9 EdgarCHN

The EdgarCHN sensitivity is not a zero-out simulation, but instead uses alternative data in China. Instead of using the THU China emissions, for EdgarCHN we use the HTAP emissions projected to 2014 using CEDS factors. In other words, in EdgarCHN, China is treated the same way as other countries outside North America. “Edgar” refers to the Emissions Database for Global Atmospheric Research, which includes the HTAP v2 dataset used for this study.

For the EdgarCHN case, we exclude all THU China sector emissions. We then reprocess all HTAP sectors which were affected by China zero-outs in the base case: g_ag, g_energy, g_industry, g_residential, and g_transport. Instead of zeroing out China emissions in those sectors, for EdgarCHN we keep all China emissions, and also apply 2010-to-2014 growth factors from the CEDS dataset (see Section 2.1.5). In the base case, we did not zero out China emissions from the HTAP aircraft or shipping sectors, so those sectors’ emissions can be reused from the base case without reprocessing.

Other than the HTAP and THU China sectors, the EdgarCHN case is equivalent to the base case, including fires and biogenics in China.

Figure 3-9. Percent difference NOx(left) and SO2(right) weekday-summer emissions for EdgarCHN sensitivity run.



4 Emission summaries

Table 4-1 summarizes emissions for the 2016 hemispheric modeling platform by sector for the entire 108km hemispheric modeling domain. The afdust and othafdust sector emissions represent the summaries *after* application of both the land use (transport fraction) and meteorological adjustments; therefore, these sectors are called “afdust_adj” and “othafdust_adj” in these summaries. The onroad sector totals are post-SMOKE-MOVES totals, representing air quality model-ready emission totals. CARB emissions for California are reported under the onroad_ca_adj sector. For CMV, the cmv_c1c2 and cmv_c3 sectors include emissions in U.S. state and federal waters, the othar sector includes CMV emissions in Canadian waters, and the g_ships sector includes CMV emissions elsewhere. Table 4-2 shows annual domain total emissions for each of the sensitivity cases.

Table 4-1. Domain total emissions by sector for 2016 hemispheric platform, tons/year

Sector	Includes	CO	NH3	NOX	PM10	PM2.5	SO2	VOC
afdust_adj	Continental U.S.				6,216,650	874,142		
ag	U.S.		2,778,508					180,293
cmv_c1c2	U.S. state+federal waters	116,380	335	611,167	17,366	16,713	580	10,842
cmv_c3	U.S. state+federal waters	57,469	97	596,900	19,212	17,797	15,919	26,072
nonpt	U.S.	2,754,695	122,447	767,493	618,831	504,676	164,401	3,734,585
nonroad	U.S.	12,425,503	2,282	1,209,937	123,000	116,208	2,448	1,513,284
np_oilgas	U.S.	646,802	15	680,416	17,847	17,580	39,132	3,020,375
onroad	Continental U.S. except California	19,646,578	87,562	3,815,719	251,155	120,018	25,654	1,857,060
onroad_ca_adj	California	799,749	13,667	230,117	21,700	10,245	1,702	104,935
onroad_can	Canada + AK/HI/PR/VI	2,305,624	9,519	481,221	29,091	20,552	1,746	203,278
onroad_mex	Mexico	6,297,363	10,351	1,501,683	74,477	57,028	26,521	554,751
othafdust_adj	Canada + AK/HI/PR/VI				2,461,411	476,986		
othar	Canada + Mexico	6,068,987	1,393,414	1,414,212	1,059,151	680,593	67,747	5,050,225
othpt	Canada + Mexico	2,353,692	57,497	1,844,920	399,581	263,139	3,402,750	1,338,420
pt_oilgas	U.S.	238,554	4,385	450,675	13,724	12,618	43,909	183,275
ptagfire	U.S.	593,082	80,365	18,298	96,340	68,103	5,636	36,121
ptegu	U.S.	672,384	25,018	1,289,229	171,237	140,845	1,544,799	33,467
ptfire	U.S.	37,941,136	621,241	441,988	3,792,193	3,213,737	261,975	8,930,350

Sector	Includes	CO	NH3	NOX	PM10	PM2.5	SO2	VOC
ptfire_othna	Canada, Mexico, Central America, Caribbean	18,814,941	308,314	725,893	2,595,963	1,841,790	137,980	5,410,402
ptnonipm	U.S.	1,879,574	61,825	1,136,271	414,564	268,625	723,900	817,149
rail	U.S.	118,925	364	675,285	20,806	19,227	702	34,874
rwc	U.S.	2,121,291	15,514	30,856	317,792	317,266	7,754	341,934
beis	Continental U.S. and vicinity	9,956,463		1,961,185				58,179,072
g_biog	Entire domain except Continental U.S. vicinity	34,386,775		16,252,008				260,825,447
g_ag	Outside US/CAN/MEX/China		27,053,284					
g_ptfire	Outside North America	121,285,767	2,005,131	6,058,488	21,767,734	13,499,258	780,250	34,654,568
g_ptagfire	Outside North America	25,959,983	382,301	1,576,886	2,362,013	1,847,549	150,067	9,932,375
g_air_cds	Entire domain	134,140		1,089,169	18,439	18,439	92,194	31,552
g_air_crs	Entire domain	179,798		1,457,442	24,682	24,682	123,425	42,107
g_air_lto	Outside US/CAN	116,928		282,723	2,350	2,350	26,785	4,415
g_energy	Outside US/CAN/MEX/China (includes CO in China)	8,597,034	71,485	14,168,795	4,951,791	2,077,552	26,978,678	884,267
g_industry	Outside US/CAN/MEX/China (includes CO in China)	132,095,290	992,589	6,997,163	6,873,446	3,563,763	16,333,374	38,620,852
g_residential	Outside US/CAN/MEX/China (includes CO in China)	232,141,408	4,546,822	4,344,817	15,661,354	11,074,589	3,478,108	33,272,813
g_ships	Outside US Federal Waters	1,175,509		12,078,998	1,207,008	1,207,008	6,633,296	628,816
g_transport	Outside US/CAN/MEX/China (includes CO in China)	99,498,142	189,347	24,530,368	1,827,155	1,678,990	1,621,702	23,083,023
china_agrf	China		4,105,865					
china_agrl	China		6,164,346					
china_dobi	China			247,159	1,535,996	1,487,994	37,311	247,159
china_docb	China							2,254,033
china_dofu	China			684,444	2,030,505	977,311	3,894,725	684,444
china_doso	China							1,863,873
china_doth	China		741,314					213,655
china_incb	China			2,520,744	1,453,406	965,475	5,920,805	2,653,154
china_ppcb	China			4,390,020	1,175,701	702,486	4,992,558	4,390,020
china_prce	China			2,100,046	1,370,862	757,175	1,005,509	2,100,046
china_prir	China			603,922	1,300,269	939,834	836,222	603,922
china_prso	China							5,792,690
china_prot	China		353,494	2,389,083	1,591,475	1,014,461	1,881,593	7,557,787
china_trof	China			2,684,613	219,988	208,409	159,214	3,354,114
china_tron	China			8,385,993	405,461	384,119	22,164	15,460,059
lightning	Entire domain			30,860,577				
TOTAL	**Entire domain**	**781,379,966**	**52,198,696**	**163,586,924**	**84,511,726**	**51,489,332**	**81,443,235**	**540,715,955**

Table 4-2. Domain total emissions for 2016 hemispheric sensitivity cases, tons/year

	CO	NH3	NOX	PM10	PM2.5	SO2	VOC
Base case	**781,379,966**	**52,198,696**	**163,586,924**	**84,511,726**	**51,489,332**	**81,443,235**	**540,715,955**
ZANTH	205,815,303	2,661,361	55,994,576	26,485,224	17,144,907	1,053,965	363,772,982
ZROW	263,425,215	6,103,894	68,276,616	36,393,852	20,982,070	3,797,678	379,286,276
ZUSA	723,767,414	48,756,163	151,287,174	74,602,782	47,651,854	78,697,944	525,202,275
ZSHIP	780,131,216	52,198,364	150,753,319	83,277,710	50,257,391	74,788,669	540,053,998
ZCHN	591,973,607	40,781,009	139,226,575	73,209,207	43,875,407	62,661,852	492,117,370
ZIND	701,221,898	40,811,982	151,620,782	74,049,474	43,936,446	69,579,876	520,341,737
ZCANMEX	763,590,698	50,710,585	158,220,989	80,426,511	49,928,210	77,930,685	533,105,441
ZFIRE	576,785,057	48,801,345	154,765,370	53,897,483	31,018,895	80,107,326	481,752,138
EdgarCHN	781,379,966	51,173,214	173,025,698	92,178,616	57,909,585	96,907,344	521,767,906

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