2020 National Emissions Inventory Technical Support Document: Agriculture – Fertilizer Application

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U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Air Quality Assessment Division
Research Triangle Park, NC

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9.1 Sector Descriptions and Overview

Fertilizer in this category refers to any nitrogen-based compound, or mixture containing such a compound, that is applied to land to improve plant fitness. The SCCs that compose this sector in the 2017 NEI are provided in Table 9-1. The SCC level 1, 2 and 3 description is “Miscellaneous Area Sources; Agriculture Production – Crops; Fertilizer Application” for both SCCs. EPA-estimated emissions are solely for SCC 2801700099, which comprise the majority of the emissions for this sector and for which EPA methods are discussed further below. The first SCC in Table 9-1 is included for completeness only, as EPA does not provide any estimates that are housed in that SCC nor did SLT submit any data for that SCC in the 2020 NEI cycle. The only pollutant estimated by EPA for this sector and expected to be reported by any SLT is ammonia (NH3).

Table 9-1: SCCs in the Agricultural Fertilizer Application sector

SCC	SCC Level 4 Description	EPA	S/L/T
2801700000	Total Fertilizers		
2801700099	Miscellaneous Fertilizers	X	X

9.2 Sources of data

The agricultural fertilizer application sector includes data from the S/L/T agencies and the default EPA-generated agricultural fertilizer emissions. The agencies listed in Table 9-2 submitted emissions for this sector; agencies not listed used EPA estimates for the entire sector.

Table 9-2: Agencies that submitted fertilizer application NH_3 emissions in the 2020 NEI

Region	Agency	S/L/T
3	Delaware Department of Natural Resources and Environmental Control	State
9	Maricopa County Air Quality Department	Local
10	Coeur d'Alene Tribe	Tribe
10	Kootenai Tribe of Idaho	Tribe
10	Nez Perce Tribe	Tribe
10	Shoshone-Bannock Tribes of the Fort Hall Reservation of Idaho	Tribe

9.3 EPA-developed estimates

9.3.1 Methodology overview

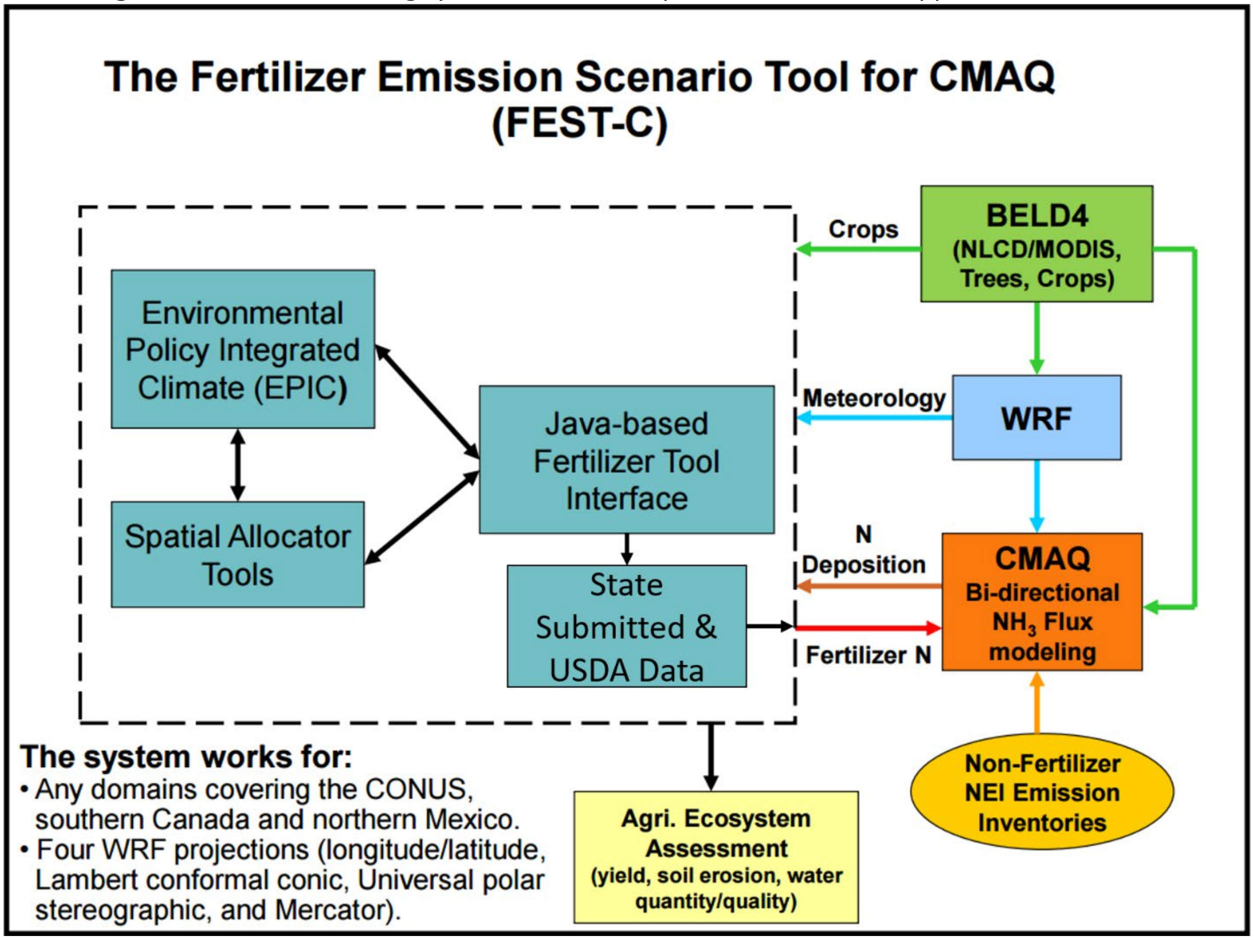
Direct flux measurements of ammonia (NH_3) over agricultural fields and natural vegetation over the past few decades have demonstrated that vegetation and soil can either be a source or a sink of atmospheric NH_3. The direction and magnitude of the exchange depends on the concentration gradient between the canopy and the atmosphere. The bidirectional approach taken here accounts, in the most comprehensive way possible, for estimated NH_3 emissions from this complex process. The NH_3 emissions estimated here are for fertilizer that has been applied to the soil. Emissions from the application processes are also estimated in the manure management portion of livestock emissions. Based on the methods used by EPA for estimating both sets of these emissions, it is believed that there is no significant double counting across the two ag sectors. The approach to calculating emissions from this sector in 2020 is very consistent with the way it was done in the 2017 NEI, with some noted embellishments to the methods for the 2020 NEI, which have resulted in about a 60% increase in NH3 emissions nationwide compared to 2017 estimates. The bidirectional version of CMAQ (v5.4) [ref 1] and the Fertilizer Emissions Scenario Tool for CMAQ FEST-C (v1.4) [ref 2, ref 3, ref 4] were used to estimate ammonia (NH_3) emissions from agricultural soils. These estimates were then loaded into EIS for use in the 2020 NEI. The approach to estimate 2020 fertilizer emissions consists of these aggregate steps:

- Run FEST-C to produce nitrate (NO_3), Ammonium (NH_4^+, including Urea), and organic (manure) nitrogen (N) fertilizer usage estimates
- CMAQ model with bidirectional ("bidi") NH_3 exchange to generate gaseous ammonia NH3 emission estimates.
- Calculate county-level emission factors as the ratio of bidirectional CMAQ NH_3 fertilizer emissions to FEST-C total N fertilizer application.
- Assign the NH3 emissions to one SCC: "…Miscellaneous Fertilizers" (2801700099).

We first estimate fertilizer application by crop type for 2020 using FEST-C modeled data. 2020 USDA Economic Research Service crop specific fertilization data is not yet available, and we also did not receive state estimated data. However, upgraded use of FEST-C v1.4 simulations resulted in better agreement with USDA ERS (Economic Research Service) and U.N Food and Agriculture national fertilizer application estimates [ref 4] with an average domain wide bias of -10.5% for 2002 to 2019 model simulations were observational data were available. Then we ran the CMAQ v5.4 model with the Surface Tiled Aerosol and Gaseous Exchange (STAGE) deposition option with bidirectional exchange to estimate fertilizer and biogenic NH_3 emissions for 2020. We use this approach for three reasons: (1) FEST-C estimates fertilizer applications based on crop nutrient needs which is typically lower than real world fertilization rates; (2) FEST-C fertilizer timing and application methods are assumed to be correct; and (3) If available, this CMAQ model option allows us to incorporate state-submitted and USDA reported data into the final fertilization emission estimates.

FEST-C is the software program that processes land use and agricultural activity data to develop inputs for the CMAQ model when run with bidirectional exchange. FEST-C reads land use data from the Biogenic Emissions Landuse Dataset (BELD), meteorological variables from the Weather Research and Forecasting model [ref 5], and nitrogen deposition data from a previous or historical average CMAQ simulation. FEST-C, then uses the USDA's Environmental Policy Integrated Climate (EPIC) modeling system [ref 4] to simulate the agricultural practices and soil biogeochemistry and provides information regarding fertilizer timing, composition, application method and amount. Figure 9-1 provides a comprehensive flowchart of the complete EPIC/FEST-C/WRF "bidi" modeling system.

Figure 9-1: "Bidi" modeling system used to compute 2020 Fertilizer Application emissions

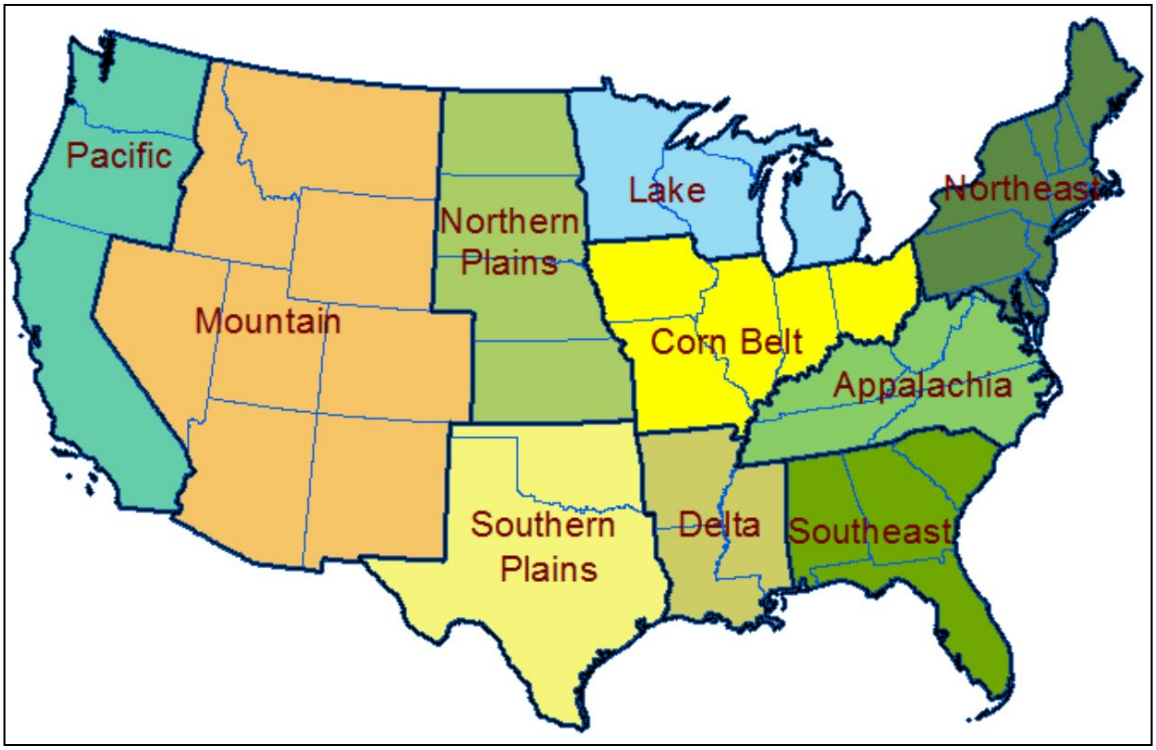


9.3.2 Activity data

The following activity parameters were input into the EPIC model:

- Grid cell meteorological variables from WRF
- Initial soil profiles/soil selection
- Presence of 21 major crops: irrigated and rain fed hay, alfalfa, grass, barley, beans, grain corn, silage corn, cotton, oats, peanuts, potatoes, rice, rye, grain sorghum, silage sorghum, soybeans, spring wheat, winter wheat, canola, and other crops (e.g., lettuce, tomatoes, etc.)
- Fertilizer sales to establish the type/composition of nutrients applied
- Management scenarios for the 10 USDA production regions shown in Figure 9-2 [ref 3, ref 4]. These include irrigation, tile drainage, intervals between forage harvest, fertilizer application method (injected versus surface applied), and equipment commonly used in these production regions.

Figure 9-2: USDA farm production regions used in FEST-C simulations



We used the WRF meteorological model to provide grid cell meteorological parameters for 2020 using a national 12-km rectangular grid covering the continental U.S. The meteorological parameters in Table 9-3 below were used as EPIC model inputs.

Table 9-3: Environmental variables needed for an EPIC simulation

EPIC input variable	Variable Source
Daily Total Radiation (MJ m^2)	WRF
Daily Maximum 2-m Temperature (C)	WRF
Daily minimum 2-m temperature (C)	WRF
Daily Total Precipitation (mm)	WRF
Daily Average Relative Humidity (unitless)	WRF
Daily Average 10-m Wind Speed (m s^{-1})	WRF
Daily Total Wet Deposition Oxidized N (g/ha)	CMAQ
Daily Total Wet Deposition Reduced N (g/ha)	CMAQ
Daily Total Dry Deposition Oxidized N (g/ha)	CMAQ
Daily Total Dry Deposition Reduced N (g/ha)	CMAQ
Daily Total Wet Deposition Organic N (g/ha)	CMAQ

Initial soil nutrient and pH conditions in EPIC are based on the 1992 USDA Soil Conservation Service (CSC) Soils-5 survey. While this survey may seem outdated, it would not be expected that much change would occur over time for these parameters as they have a typically fairly narrow range of pH requirements and soil pH that is managed by the farmer. The EPIC model then is run for 25 years using current fertilization and agricultural cropping techniques to estimate soil nutrient content and pH for the 2020 EPIC/WRF/CMAQ simulation.

The presence of crops in each model grid cell was determined using USDA Census of Agriculture data (2006) and USGS National Land Cover data (2011). These two data sources were used to compute the fraction of agricultural land in a model grid cell and the mix of crops grown on that land.

Fertilizer sales data and the 6-month period in which they were sold were extracted from the 2014 Association of American Plant Food Control Officials (AAPFCO). AAPFCO data are used to identify the composition (e.g., urea, nitrate, organic) of the fertilizer used, and the amount applied is estimated using the modeled crop demand. These data are useful in making a reasonable assignment of what kind of fertilizer is being applied to which crops.

Management activity data refers to data used to estimate representative crop management schemes. We used the USDA Agricultural Resource Management Survey (ARMS) to provide management activity data. These data cover 10 USDA production regions shown in Figure 9-2 and provide management schemes for irrigated and rain fed hay, alfalfa, grass, barley, beans, grain corn, silage corn, cotton, oats, peanuts, potatoes, rice, rye, grain sorghum, silage sorghum, soybeans, spring wheat, winter wheat, canola, and other crops (e.g., lettuce, tomatoes, etc.).

The following variables were provided to stakeholders to enable review, comment, and potential improved localized inputs on these data in the 2020 NEI process:

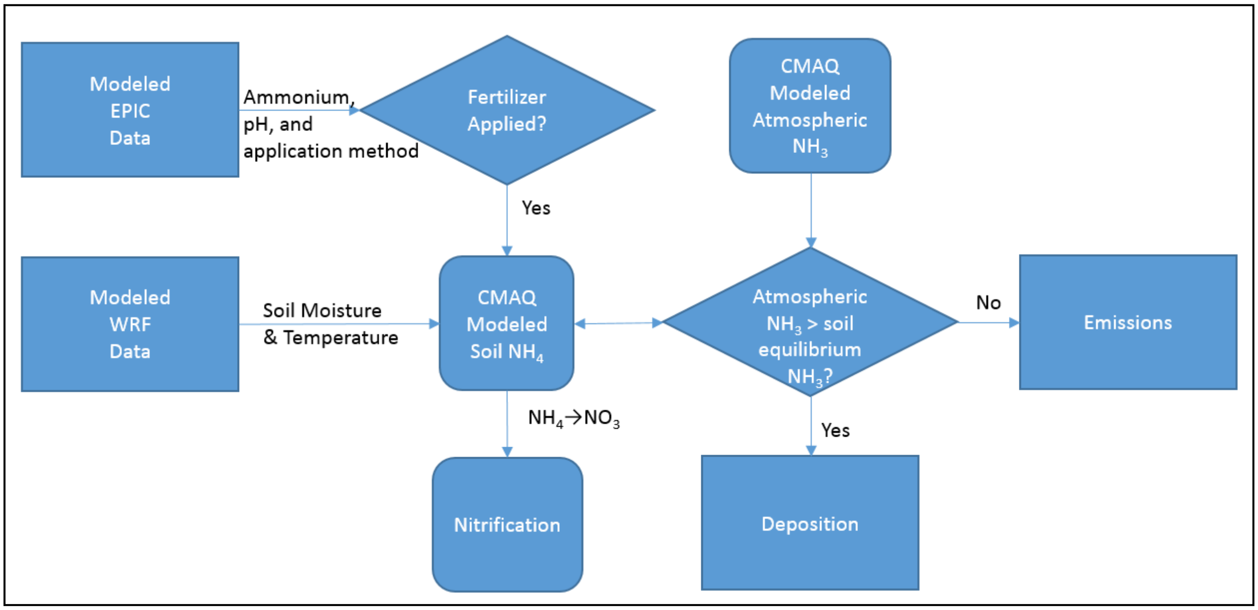
- Fertilizer application timing
- Plant/harvest dates
- Fertilizer application rates by crop and county
- Area planted
- Crop yields

9.3.3 Emission factors

The emission factors were derived from the 2020 CMAQ FEST-C outputs. Total fertilizer emission factors for each month and county were computed by taking the ratio of total fertilizer NH_3 emissions (short tons) to total nitrogen fertilizer application (short tons).

12 km by 12 km gridded NH_3 emissions were mapped to a county shape file polygon. The cell was assigned to a county if the grid centroid fell within the county boundary. County-level fertilizer emissions (NH3) for 2020 are subsequently derived from the diagnostic emission output from a 2017 CMAQ FEST-C model simulation [ref 9]. With this modeling system, it would be difficult to perform a sample calculation as part of this documentation. These emissions are computed via the full chemical transport model, as illustrated in Figure 9-3.

Figure 9-3: Simplified FEST-C system flow of operations in estimating NH_3 emissions



9.3.4 Improvements/Changes in the 2020 NEI

The 2020 fertilizer emission estimates are based on the CMAQ FEST-C "bidirectional" approach outlined in Figure 9-1 and Figure 9-3 that couples meteorological inputs, CMAQ, and the EPIC modeling system through the FEST-C interface. The approach used for estimating ammonia emissions for the 2020 NEI is substantially the same approach as that used for the 2017 NEI efforts, which is documented in the 2017 NEI TSD. However, the 2020 NEI used the latest model versions of CMAQv5.4 and FEST-Cv1.4. FEST-Cv1.4 largely corrected bugs in FEST-Cv1.3 correcting the indexing of modeled beans and canola crop types. The estimates used FEST-Cv1.4 simulations with CMAQv5.4 using the land use specific deposition option, Surface Tiled Aerosol and Gaseous Exchange (STAGE), and bidirectional NH_3 exchange. In addition, the following substantial changes were made in estimating NH_3 emissions using this process in the 2020 NEI:

- Revised/improved treatment of the biogenic non-agricultural emissions based on recent observations from ORD measurement programs [ref 6, ref 7].
- The CMAQ look up table of plant functional type, e.g., evergreen needleleaf forests, emission factors were updated in CMAQv5.4 based on soil and vegetation surveys at some AMoN sites and soil and vegetation and soil NH_4^+ observations in the global TRY plant trait database (https://www.try-db.org)
- These updates resulted in significantly higher emission factors for soils for all land cover types except evergreen needle leaf forest and increases in the vegetation emission factors for grasslands. These data were used to update the emission factors for no-agriculture land use in CMAQ that were previously populated based soil measurements from a North Carolina pine forest and vegetation NH_4^+ estimated from annual deposition fields from CMAQv5.0 simulations and the empirical relationship in Massad et al. [ref 8] as documented in Bash et al. [ref 9, ref 10].
- Moving from MODIS to 2011 NLCD datasets for national coverage of agricultural lands resulted too in contributing to an overall increase in to 2020 emissions
- The national coverage of Agriculture between NLCD and MODIS is similar, but MODIS estimates much larger coverage for the upper midwest, where we see the decrease in NH_3 emissions and NLCD has much higher agriculture coverage KS, OK, North TX, and the southeast.

Due to all these changes/ improvements made to the emissions estimation process in the 2020 cycle, nationwide EPA NH3 estimates for this sector are about 60% higher than in 2017. In the 2017 NEI, about 1.1 million tons of NH3 were estimated in total from this source, in the 2020 NEI that number increases to about 1.8 million tons. Please note that in the 2017 NEI for this sector, emissions were reported incorrectly as "tons of N" instead of NH3, making the correction for converting "tons of N" to NH3 results in the 1.1 million tons number referenced above. Figure 9-4 shows how these emissions are distributed by county (note that AK and HI are blank as EPA methods do not cover that domain and we did not receive any submissions from those states), and Figure 9-5 shows the difference county by county of emissions in 2020 vs emissions in 2017. It can be seen from Figure 9-5 that most counties showed an increased level of emissions in 2020 compared to 2017. By state, the biggest increases in moving to 2020 for states with higher absolute amounts of NH3 emissions include FL, GA, MO, SC, and AL. States that decreased in emissions in going to 2017 from 2020 were few, but included WA, MN, ID, and AZ.

Figure 9-4: Distribution of Ag Fertilizer NH3 emissions in the 2020 NEI

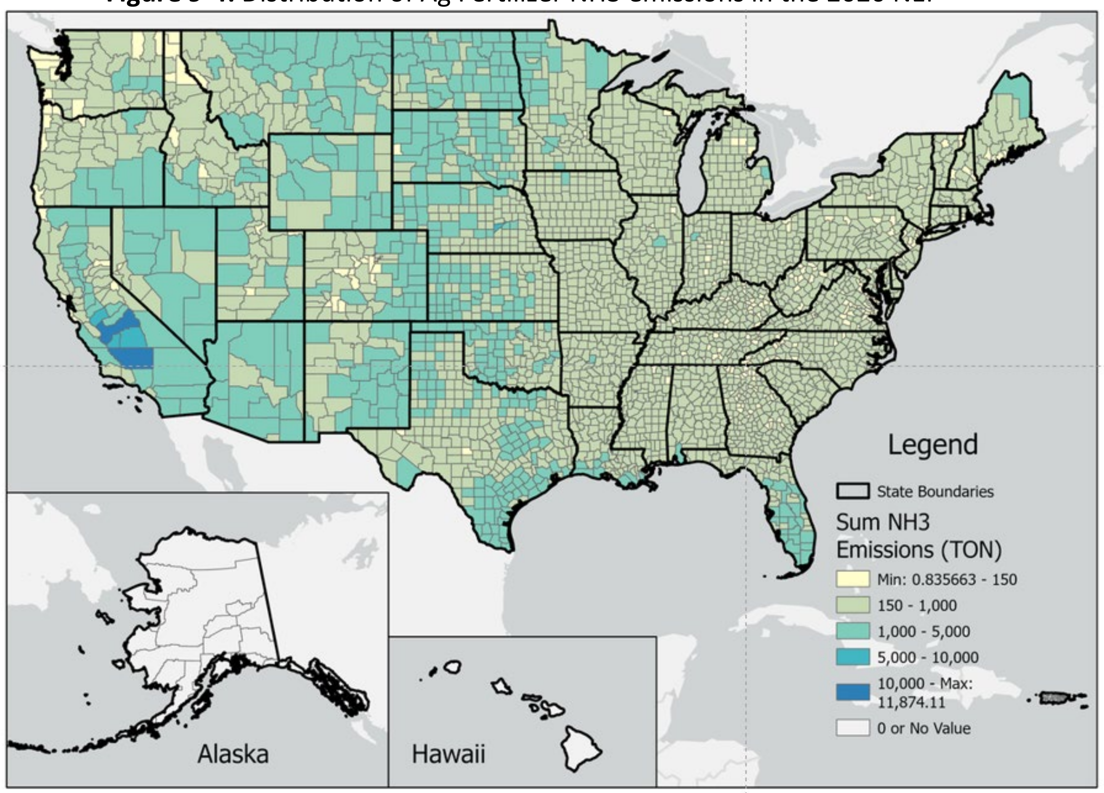
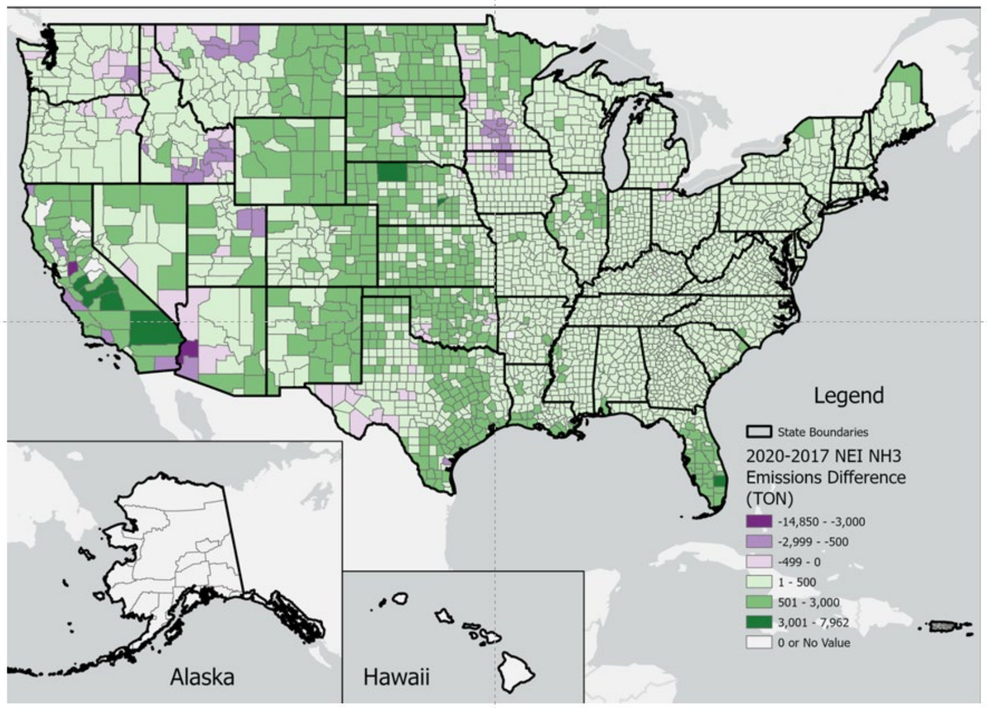
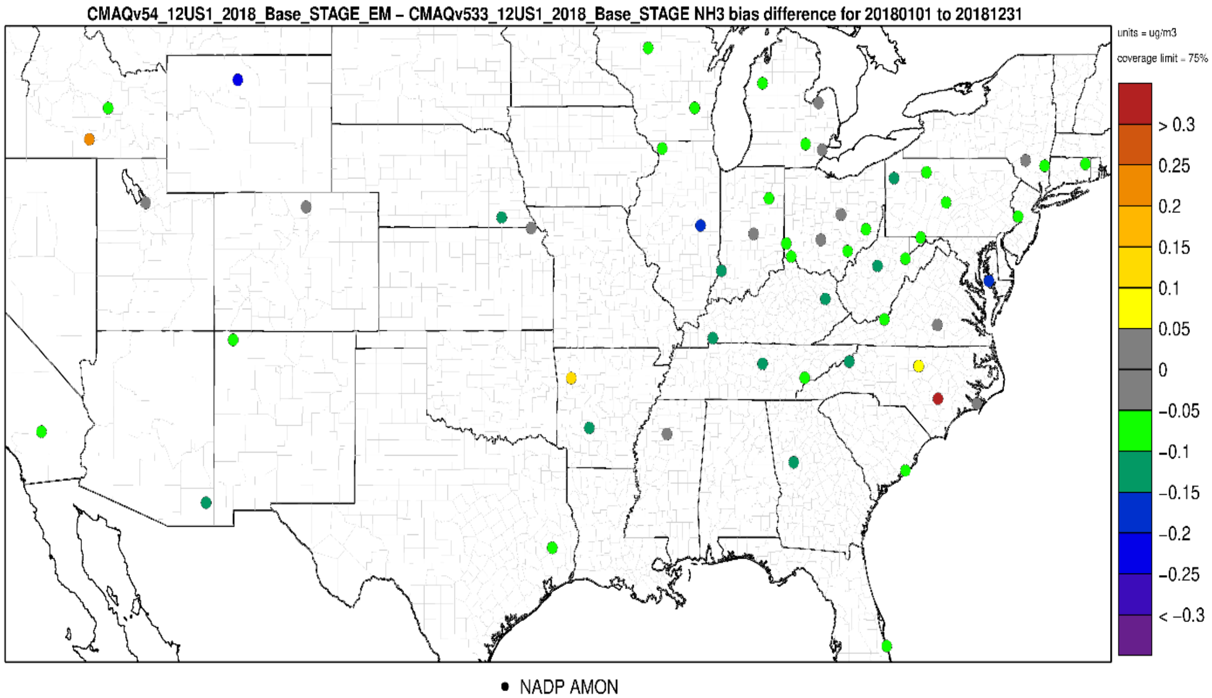


Figure 9-5: NH3 emissions difference between 2020 NEI and 2017 NEI, by county



To check the validity of these increases in ammonia emissions going from 2017 to 2020, a CMAQ model simulation for the year 2018 was used to evaluate these natural ammonia emission potential increases (via new measured emissions factors as discussed previously) and these simulations resulted in a lower model bias at 84% of AmON NH3 monitoring sites (see Figure 9-6 which shows modeled concentrations of NH3 compared to monitored values of NH3) and reduced the summertime model NH3 bias from -29% to -17% (still an underestimate but better). In Figure 9-6, the cooler colors indicate a reduction in model bias at those locations.

Figure 9-6: Model evaluation of air quality based on updated ag fertilizer emissions



There is no point source subtraction that is needed for this sector. Additional Information regarding the general methods employed here can be found in the Air Emissions Inventory Training site, search for "Key Ammonia sectors" training materials.

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