**WRF/EPIC/CMAQ Factsheet**

*February 25, 2016*

**Application of EPA’s “One Biosphere Modeling System” to estimate NH3 emissions from cropping systems**

**WRF/EPIC/CMAQ NH3 Emissions**

Recent modeling advancements have led to the development of tools for policy relevant scenario analysis that more accurately portray air, land and water interactions with agricultural systems. For instance, Bash et al. (2013) and Cooter et al. (2012) demonstrate that coupling atmospheric reduced nitrogen pools with temporally resolved agricultural soil and vegetation nitrogen pools improves regional estimates of atmospheric particulate matter and nitrogen deposition loading to underlying land and water surfaces over previous uncoupled estimates. The inclusion of agricultural cropping practices and coupling of soil-, vegetative-, and atmospheric pools of reduced nitrogen in the Community Multiscale Air Quality (CMAQ) model can expand the capabilities of air-quality modeling systems and improve estimates of atmospheric particulate matter and nitrogen deposition loading. Previously, CMAQ modeled the net flux of ammonia (NH3) between the atmosphere and terrestrial or aquatic lands. The added capabilities produce files for diagnostic NH3 emission and deposition.

To produce these emission and deposition outputs, the modeling system relies on the coupling of the Weather Research Forecast (WRF) meteorological model, CMAQ and the Environmental Policy Integrated Climate (EPIC) modeling system. The EPIC model provides information regarding fertilizer timing, composition, application method and amount. CMAQ has been updated to model the soil geochemistry related to the ammonium (NH4) component of the fertilizer. Modeled NH3 emissions are modeled as a function of the soil geochemistry (nitrification), soil emissions, re-emission of deposited ammonia and vegetative uptake or emissions. Thus, the emission factors for fertilizer application are dynamic in space and time. Changes or improvements are driven by changes or improvements to the EPIC fertilizer input. Improvements in NH3 emissions in this modeling system, can be accomplished by evaluating EPIC estimates of crop specific data, e.g. yield, fertilizer application, planting or harvest date, etc, and adjusting the corresponding modeled agricultural management.

**EPIC Fact Sheet**

The EPIC model is a field scale, semi-empirical, process-based, biogeochemical farm management model developed by USDA and now housed and maintained by Texas A & M AgriLife Research Center. EPIC simulates the response of soil and plant productivity in response to weather and management drivers. It can simulate fields up to 100 ha in extent and runs on a daily time step. Original EPIC descriptions, code and documentation are available for download at: <http://epicapex.tamu.edu>

This code has been modified by EPA scientists working closely with retired EPIC developers to directly support research and data input needs of the bidirectional ammonia version of CMAQ5.1 and EPA/ORD research scientists. All input files are created and output files are managed using a JAVA-based interface tool, the Fertilizer Emissions Scenario Tool for CMAQ (FEST-C). FEST-C, which includes the EPA implementation of EPIC, is documented and available for public download at: <http://www.cmascenter.org>

The EPA implementation is typically run at a 12km rectangular grid resolution for grid cells contained within the boundaries of the United States. The interface supports any CMAQ US domain definition and grid resolution. Table 1 provides information regarding data inputs to EPIC. Table 2 provides a list or relevant EPIC output information. Table 3 lists evaluated EPIC simulation results.

As is the case for CMAQ, the application of the modeling system is at a regional scale. FEST-C takes advantage of EPIC’s process structure and relies very little on direct input of historical or point-specific data. We assume that all agricultural management takes place on “typical” soils for each crop/grid cell. Within EPIC, simulated fertilizer application amounts and timing, as well as crop plant and harvest dates, are dictated by the local weather and the simulated plant nutrient needs by crop at specific model grid cells. EPIC fertilizer estimates are based on a plant growth nutrient need model and applied optimally in the growth cycle. As a consequence, the regional fertilizer application predicted here should be considered physically reasonable, but likely conservative relative to actual practice.

**Table 1. EPIC inputs**

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| INPUT | SOURCE/DESCRIPTION |
| Grid cell weather | Weather Research Forecast (**WRF**) model results; same inputs as those driving **CMAQ** |
| Initial soil Profiles/Soil Selection | National Resource Inventory (NRI) reported “typical” crop soil association by 8-digit HUC; soil datasets were built to represent the sample point soils selected for the 1997 USDA Natural Resources Inventory (NRI) data points. These data points are represented by a subset of almost 23,000 soils with complete parameter data. A 25-yr simulation is run for each crop, soil and management set in each model grid cell to develop appropriate initial soil characteristics. |
| Crop presence | USDA Census of Agriculture (County Statistics) and USGS National Land Cover Data Layer are used to determine the fraction of agricultural land in a model grid cell and the mix of crops grown on that land. |
| Fertilizer sales data | The types of fertilizers sold and the 6-month period in which they are sold are extracted (Association of American Plant Food Control Officials, AAPFCO). This information is used to make a reasonable assignment of what kind of fertilizer is being applied to which crops. This is important for the estimation of application depth which influences the fraction of applied N that is emitted. |
| Management | USDA Agricultural Resource Management Survey (ARMS) data for each of 10 USDA production regions are used to estimate representative management schemes for each crop grown in each production region. |

**Table 2. FEST-C Outputs**

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| --- | --- |
| OUTPUT | DESCRIPTION |
| Crop types | FEST-C is configured to estimate properties for the following irrigated and rain fed crops (a total of 42): 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. |
| Soil chemistry | FEST-C outputs soil NH4, NO3 and organic carbon content for each crop and soil combination assigned to a modeled 12 km grid cell. |
| Fertilizer Application | FEST-C estimates the time, amount, and application type (surface applied or injected) of NO3, Ammonium (including Urea), and organic (manure) nitrogen fertilizers for each crop. |
| Management | FEST-C estimates the crop planting date, fertilizer application method, fertilizer timing, and harvest date for each crop simulated. All simulated fertilizer applications follow a “right time, right place, right amount” paradigm and so they represent a reasonable lower bound (conservative) application estimate. |
| Agricultural | Agricultural yield is estimated for each crop type. Predicted yield includes reductions associated with drought, floods, and insufficient nutrient supply, salt and aluminum toxicity. Pest and pathogen-related yield reductions are not addressed. |

**Table 3. Evaluation FEST-C/EPIC results for general applications.**

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| Output Variable | Evaluation Source |
| Plant and Harvest Dates simulated using a 10-day activity window | Weekly Crop and Weather Bulletin, cumulative State-level activity. |
| Rainfed and Irrigated Crop Yields | USDA Census of Agriculture State-level Data |
| Nitrogen Application | USGS (2002-2006), USDA |

**Related Publications**

Bash, J.O., Walker, J.T., Shephard M.W., Cady-Pereira, K.E., Henze, D.K., Schwede, D., Zhu, L., Cooter, E.J., Modeling reactive nitrogen in North America: recent developments, observational needs and future directions, *EM,* September 2015

Bash, J.O., Cooter, E.J., Dennis. R.W., Walker, J.T., Pleim. J.E.; Evaluation of a regional air-quality model with bi-directional NH3 exchange coupled to an agro-ecosystem model, *Biogeosciences,* 10, 1635-1645, 2013

Cooter, E.J., Bash, J.O., Benson V., Ran, L.-M.; Linking agricultural management and air-quality models for regional to national-scale nitrogen deposition assessments, *Biogeosciences*, 9, 4023-4035, 2012

Flechard, C.R., Massad, R.-S., Loubet, B., Personne, E., Simpson, D., Bash, J.O., Cooter, E.J., Nemitz, E., Sutton, M.A.; Advances in understanding, models and parameterizations of biosphere-atmosphere ammonia exchange, *Biogeosciences*, 10, 5183-5225, doi: 10.5194/bg-10-5183-2013, 2013

Pleim, J.E., Bash, J.O., Walker, J.T., Cooter, E.J.; Development and testing of an ammonia bi-directional flux model for air-quality models, *J. Geophys. Res.* 118, doi:10.1002/jgrd.50262, 2013

Sutton, M.A., Reis, S., Riddick, S.N., Dragosits, U., Nemitz, E., Theobald, M.R., Tang, Y.S., Braban, C.F., Vieno, M., Dore, A.J., Mitchell, R.F., Wanless, S., Daunt, F., Fowler, D., Blackall, T.D., Milford, C., Flechard, C.R., Loubet, B., Massad, R., Cellier, P., Coheur, P.F., Clarisse, L., van Damme, M., Ngadi, Y., Clerbaux, C., Skøth, C.A., Geels, C., Hertel, O., Wickink Kruit, R.J., Pinder, R.W., Bash, J.O., Walker, J.T., Simpson, D., Horvath, L., Misselbrook, T.H., Bleeker, A., Dentener, F., de Vries, W.; Toward a climate dependent paradigm of ammonia emission and deposition, *Phil. Trans. R. Soc. B*, 368: 20130166, 2013

Walker, J.T., Jones, M.R., Bash, J.O., Myles, L., Luke, W., Meyers, T.P., Schwede, D., Herrick, J., Nemitz, E., Robarge, W.; Processes of ammonia air-surface exchange in a fertilized *Zea Mays* canopy, *Biogeosciences*, 10, 981-998, 2013

Zhu, L., Henze, D.K., Bash, J.O., Cady-Pereira, K.E., Shephard, M.W., Luo, M., Capps, S.L.; Sources and impacts of atmospheric NH3: Current understandings and frontiers for modeling and measurements, *Current Pollution Reports*, 1, 95-116, doi:10.1007/s40726-015-0010-4, 2015