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Integrated Large-Scale Modeling Framework for N_2O Emissions Estimation in an Agricultural Field using Parallel Computing

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Greenhouse gas (GHG) emissions play an important role in climate change. GHG emissions consist of carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). Other than CO_2, N_2O and CH_4 should be considered because N_2O and CH_4 have a global warming potential (GWP) of 298 and 25, respectively over a 100-year timescale. A major source of N_2O is denitrification of fertilizer nitrates. A significant proportion of nitrogen supplied to crops is also ultimately converted to N_2O. Global emissions are particularly high from crops such as maize which are often grown with high fertilizer inputs and cover a large global land area, including in the United States, which leads the world in maize production (including 36.3% of global exports). Estimation of N_2O emissions at a regional to global scale can be done with mechanistic agroecosystem simulation models or through the use of simple deterministic, data-based models. Simulation models allow for the coupled analysis of emission response to exogenous factors such as management and climate but often do not generate accurate results due to the complexity of processes involved in the production of N_2O in soils. Simple deterministic models can produce higher accuracy emission estimates but lack the ability to examine responses to complex patterns in exogenous forcings and conditions. Here, we combine approaches to estimate maize yield and quantify its impact on N_2O emissions from croplands in the United States. To estimate the impact of maize production on N_2O emissions under various scenarios (i.e., different crop, management, fertilizer, and irrigation) from regional to national (with capacity for global) scales, we developed an integrated large-scale modeling framework using parallel computing. In the modeling framework, we coupled the biophysical process-based model EPIC (Environmental Policy Integrated Climate) with the Farm Energy Analysis Tool (FEAT) which is a deterministic, data-based model. We estimated N_2O emissions from maize areas. Total N_2O emissions per ha including N_2O direct, volatilization, and leaching and runoff are 1396 kg CO_2e/ha/year and total N_2O emissions per maize yield are 178.8 kg CO_2e/Mg grain. Validation results indicated that the integrated modeling framework simulated N_2O emissions well with NSE (Nash-Sutcliff Efficiency) and R^2 (Coefficient of Determination) which are 0.923 and 0.995 respectively. We also tested the performance of the modeling framework using a parallel computing system developed in this study. We compared single-core (serial processing) and 14 cores (28 threads) (parallel processing) computing time for maize areas (32,900,000 ha) in the United States with 55,808 simulation units. Serial processing requires 57.2 hours, while using the framework with 14 cores requires only 7.4 hours, an approximately 87% reduction in computing time.