MCI Project: Interim Synthesis of Regional CO_2 Fluxes

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Background

The Mid-Continent Intensive Campaign (MCI) was a concept study developed by Pieter Tans (2003)[1], focusing on a region in the Central U.S. to reduce uncertainties associated with carbon fluxes between the terrestrial surface and atmosphere. A MCI Task Force (2006)[1] developed a science plan for the MCI with four main objectives:

1. To develop "top-down" atmospheric budgets and "bottom-up" inventories to estimate fluxes and their associated uncertainties,
2. Evaluate the top-down budgets and bottom-up inventories using independent data that, for example, overlap a subset of the domain in space and/or time,
3. Compare and contrast validated bottom-up and top-down approaches and reconcile differences to the extent possible by making incremental improvements through further evaluation and improvements in both methods, and
4. Quantify sources and sinks during the campaign as well as the mechanisms governing those fluxes.

The campaign was initiated in 2007 and continues into 2008 with arguably the most intensive sampling of atmospheric CO_2 across a region that has been attempted to date. A three-year study has been funded by NASA to compile modeling results for CO_2 fluxes in the region, compare inversion and inventory estimates and reconcile the results to the extent possible. The synthesis project has been divided into two phases, including a) an interim analysis for pre-campaign years, and b) 2007-08 synthesis coinciding with the intensive sampling campaign. The interim synthesis will provide a benchmark against which to evaluate the improvement in quantifying CO_2 flux based on observations

[1] Reference documents are available at the NACP web site from the MCI campaign link.

collected in 2007 and 2008. The regional interim activity[2] has three goals: a) evaluate inventories with localized measurements from eddy-covariance flux towers, in addition to NPP estimates derived from USDA-NASS yield data in the region, b) compile both top-down inversion results and bottom-up inventories for the region, and c) make an initial comparison of inversions and inventories.

Key Research Questions

- How consistent are inventory results and atmospheric inversions for the Mid-Continent Region prior to the MCI campaign?
- Which inventory emission sources or C pools appear to be the primary sources of discrepancy with inversion results?

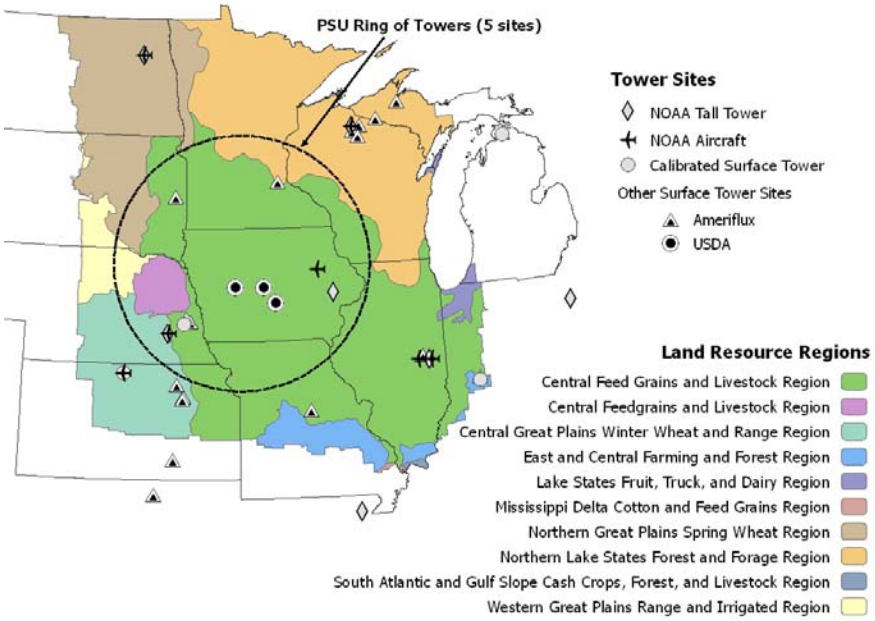

Fig 1. Mid-Continent Intensive Campaign Study Region.

Inventory

Inventory estimates will be compiled from individual submissions by investigators involved with the study (See Appendix A for list of Investigators). Key sources and pools include: fossil emissions; CO_2 flux/C stock change for plants and soils in croplands, grasslands, forestlands; livestock emissions; waste management; and human respiration.

[2] S. Verma is also conducting a synthesis of eddy-covariance flux tower results from corn and soybean systems in the region.

What is an inventory?
In the context of the MCI, the goal is to develop an inventory of CO_2 emissions and removals analogous to the conceptual framework described by the IPCC (2006)[3]. The one major difference is that the inventory produced for the MCI is intended to fully account for all emissions and removals of CO_2, regardless of whether they are influenced by anthropogenic activity. This is an important distinction because the inventories are expected to quantify the total net CO_2 flux in order to make valid comparisons with atmospheric inversions. Two general approaches will be used, including a) assessments quantifying change in C stocks over time to estimate the flux, and b) assessments that estimate the flux directly without quantifying C stocks.

According to IPCC (2006), an inventory of GHG emissions and removals can be conducted using a variety of approaches that may incorporate measurements and/or modeling. Methods can be as simple as multiplying a stock change factor for a C pool by an area for the pool (or an emission factor multiplied by an activity driving the emissions, such as fossil fuel combustion), but more sophisticated designs are also available that utilize advanced modeling techniques. Purely measurement-based approaches are also possible but rarely feasible for conducting an inventory of GHG emissions and removals over a large spatial domain.

Evaluating Inventories
Two analyses will be used to evaluate the inventories. The first will be a comparison to CO_2 flux data from eddy-covariance flux tower measurements in croplands. Given the synergy between this activity and an ongoing continental interim synthesis, MCI investigators are requested to simulate the sites from the continental synthesis activity that are coincident with the MCI region. *Protocols and driver data for this analysis will be made available at the MAST-DC website (http://nacp.ornl.gov/int_synth_site.shtml).* The following flux sites and years of data collection will be included in the evaluation:

- Rainfed and Irrigated Cropland sites at Mead, Nebraska (2001-05)
- Cropland site at Bondville, Illinois (2001-05)
- Cropland site at Rosemount, Minnesota (2004-05)[4]
- Cropland site at Lamont, Oklahoma (2003-05)
- Cropland site at Fermi Lab in Illinois (2004-05)[4]
- Grassland site at Fermi Lab in Illinois (2004-05)
- Forest site at Lost Creek, Wisconsin (2000-05)
- Forest site at Park Falls, Wisconsin (2000-05)
- Forest site at Willow Creek, Wisconsin (2000-05)
- Forest site at Sylvania, Michigan (2002-05)
- Forest site in Ozarks, Missouri (2004-05)
- Forest site at Morgan Monroe State Forest, Indiana (2000-05)
- Forest site at University of Michigan Biological Station (2000-03)

[3] 2006 IPCC 2006 National Greenhouse Gas Inventory Guidelines
[4] These location are additional sites for the MCI synthesis that are not included in the continental synthesis

The second evaluation will be based on comparing NPP estimates from cropland models with NPP derived from USDA-NASS statistics. Investigators will need to provide uncertainty along with their NPP estimates in order to facilitate this analysis.

For the interim synthesis, no evaluation is planned for grasslands, wetlands or settlements, or for other emission sources such as combustion of fossil fuels. Additional evaluation may be possible as part of the 2007-08 synthesis.

Compiling Inventories
We anticipate that most inventories will only estimate C stock change or CO_2 flux for a subset of the pools or emission sources in the region. Thus, it will be necessary to combine results in order to produce an overall inventory of CO_2 flux for comparison with the atmospheric inversions. For the interim synthesis, a regional inventory of CO_2 flux will be developed for 2000-05 with a monthly time step at a county scale. To the extent possible, separate inventories and associated uncertainties will be generated for sources and sinks with more than one contribution (e.g., soil C stocks from Ogle, West, Liu and Izzauralde). In addition, a combined inventory will be derived by averaging emissions/C stock changes from the multiple contributions, using uncertainty estimates to weight contributions. In addition, uncertainties will be combined using error propagation methods to estimate overall uncertainty.

Note: Inventories should not incorporate atmospheric CO_2 concentration measurements into the modeling framework because this would create "circularity" in comparisons with inversion results, which use the atmospheric concentration measurements as the primary source of data for inferring CO_2 flux between the earth surface and atmosphere.

To facilitate data analysis and intercomparison, investigators are requested to follow the specific guidelines for data submission provided in Appendix B. MAST-DC (Bob Cook) will coordinate submissions, and provide the data to CSU scientists for analyses (S. Ogle, S. Denning and D. Cooley).

Key Deadlines:
Investigator C stock change/emissions data to MAST-DC – October 20, 2008
Inventory Compilation Completed – November 3, 2008

Atmospheric CO_2 Inversion
Atmospheric CO_2 inversions will be produced for 2000 to 2005 and compared with the inventory results. The inversion will be on a monthly time step at a 1x1 degree resolution. While this is a rather coarse scale, pre-MCI campaign inversions were not routinely done at finer scale due to the sparse atmospheric sampling network. For the campaign years, the sampling is considerably denser in the region, and it is anticipated that these data will provide a basis for generating finer scale inversions at a 10 km scale. Moreover, one of the goals of the MCI is to evaluate the adequacy of the more intensive sampling regimes for producing finer scale inversions with sufficient precision and accuracy.

Given the synergy with the continental synthesis activity, submissions will follow the protocol developed for this related activity. *The inversion data submission protocol is available at the MAST-DC website (http://nacp.ornl.gov/int_synth_contreg.shtml).* Inversions within the MCI domain will be combined for comparisons to the inventory results. MAST-DC (Bob Cook) will coordinate data submissions, and provide results to CSU scientists for analyses (S. Ogle, S. Denning and D. Cooley).

Key Deadlines:
Investigator inversion data to MAST-DC – October 20, 2008
Combined inversion product – November 3, 2008

Diagnosis
Atmospheric inversions and inventories will be compared by computing the absolute and relative difference for each monthly time step, along with uncertainty in the estimated differences. An initial effort will be made to diagnose the differences according to relationships with surface characteristics (e.g., vegetation, indices, land cover etc.) and weather patterns; as well as the underlying sources and pools of CO_2 estimated by investigators contributing to the inventory. In addition, an interim flux product will be developed by combining the inversion and inventory results taking into consideration the uncertainties associated with each set of estimates. This product will be the benchmark for evaluating improvement with higher density of atmospheric sampling associated with the MCI campaign.

Surface Characteristics:
- Land/Water Fraction (sub-1 km resolution)
- MODIS EVI Product
- MODIS LAI Product
- MODIS Land Cover Product
- NLCD Land Cover Product
- Location of Roads and Settlements
- Location of Power Plants
- Digital Elevation Maps

The results from the analyses will provide a benchmark for the campaign synthesis of results from the campaign years of 2007-08. The interim synthesis will also serve as a learning experience to refine methods for the 2007-08 analysis.

Deadlines:
Diagnosis Results – January 31, 2008

Dissemination of Interim Synthesis Results
Results will be presented at the NACP investigator meeting in 2009 and also provide the basis for a manuscript focusing on the current findings and expectations for improving

the understanding of CO_2 fluxes in the Mid-Continent Region with data from the intensive field campaign. Participants will be invited to assist as co-authors on the manuscript.

Appendix A: Data Providers

Investigators who have agreed to provide model results for the interim study include:

- Bruce Cook – Regional Flux (N. Wisconsin region)
- M. Dietze – CO_2 flux in forestlands
- K. Gurney – fossil emissions
- L. Heath – C stock change in forestlands
- C. Izaurralde – soil C stock change in croplands
- S. Liu – soil C stock change in croplands
- E. Lokuypitiya/S. Denning – CO_2 flux in croplands
- S. Ogle/K. Paustian/C. Potter – soil C stock change in grasslands and croplands
- B. Riley/M. Fischer – Regional Flux (S. MCI region)
- C. Tonitto – soil C stock change in croplands
- T. West – soil C stock change in croplands, livestock respiration, human respiration, fossil emissions from agricultural production (for potential integration with Gurney's dataset)
- K. Davis – regional CO2 flux (VPRM, PSU)
- S. Denning – atmospheric inversions (CSU)
- A. Hirsch, A. Andrews and P. Tans – atmospheric inversions (NOAA)
- A. Michalak – atmospheric inversions (Univ. of Michigan)

Please contact Stephen Ogle (email: ogle@nrel.colostate.edu) if you are interested in providing data for the interim synthesis activity and you or a member of your research team is not listed above.

Appendix B: Inventory Submission Protocol

This protocol provides guidance for submitting inventory results for the MCI regional analysis. Investigators are requested to submit results following the protocol in this document; otherwise, it may be not possible to include the submission in the analysis due to limited resources for processing/modifying data by MAST-DC, which is providing support to the synthesis project).

The goal of the regional scale interim synthesis is to establish a benchmark that will serve as a basis for evaluating improvement in quantifying CO_2 fluxes in Mid-Continent Region with the data collected through intensive sampling campaign in 2007-08. Given the short time frame for submission and lack of funds to facilitate re-analysis, investigators are not required to re-tool their modeling framework to use identical input datasets, but rather use results that they have produced in past assessments. However, selected driver data are available through the MAST-DC website if investigators need additional data to complete simulations for the region (e.g., 1 km met data for 2000-04, http://nacp.ornl.gov/mast-dc/mast-dc_products.shtml).

The C pools and other CO_2 emission sources that are requested for the interim synthesis include:

- Fossil fuel combustion (FF)
- Biomass C (BC)
- Litter C (LC)
- Soil organic C (SOC)
- Soil inorganic C (SIC)
- Livestock respiration (LR)
- Human respiration (HR)
- Agricultural product import/export (AP)
- Forest product import/export (FP)
- Waste Management/Landfills (WM)
- CO_2 flux from Waterways/Lakes (WA)

At a minimum, investigators are requested to provide total CO_2 flux associated with the C pools (e.g., biomass C, soil C) or processes (net primary production, ecosystem respiration) and/or emission sources (e.g., fossil fuel combustion) included in their modeling framework. For investigators simulating processes rather than pools, we request that investigators list the C pools associated with those processes (e.g., NPP would be associated with biomass C). Some investigators may have estimates for several C pools/processes in addition to the total CO_2 flux associated with the pools. In such cases, investigators are welcome to provide results for each pool/process in addition to the total.

Investigators are requested to provide data at a county-scale for the MCI study region (Figure 1). A digital file is available at the MAST-DC website with the boundaries for the analysis. County-scale data will facilitate comparisons with NPP estimates derived

from NASS yield data. Investigators may also include estimates that do not provide complete county-coverage for some counties, or simply drop those counties from their submission. If they opt for the former, investigators will need to provide an approximate percentage of the spatial coverage in the county included in their estimate for the CO_2 flux (e.g., a modeling framework estimating C stocks in cropland may only represent 60% of cropland in Johnson County, IA, which would be included in a separate field/column in the file, i.e., % of county estimated).

Submission Details
Time Step: Monthly

Time Period: 2000-2005 (or as many years within this time period as possible)

Spatial Resolution: county

Spatial Extent: MCI study region (see Figure 1)

Units: *CO_2 flux and C stock estimates* in metric tonnes of CO_2 equivalent month^{-1}. For NASS yield comparisons, provide NPP estimates in metric tonnes of CO_2 equivalent per m^{-2} month^{-1}

Data File Format: The file format should be an ASCII text file with the following columns: FIPS code (available at MAST-DC website), year, month, CO_2 flux, % of spatial coverage in county, flux associated with different C stock pools (e.g., biomass, litter and soil C), NPP by crop type (list crops in separate columns), and standard deviation of mean NPP estimate. A second file(s) should be submitted with the covariance matrix for county level estimates (may require more than one file if submitting CO_2 flux for more than one source). The file name should contain the name of the model.
Note: At a minimum, investigators are requested to provide the first 4 columns of data.

Meta-Data File: Meta-data will be entered through a web-based meta-data tool designed by MAST-DC, and can be accessed at the following web address: http://daac.ornl.gov/SURVEY9/survey.shtml. The meta-data tool has required and optional sections. The required section includes the following information:

- General Information, including model name, acronym (if applicable), investigator or point of contact, email address for investigator or point of contact email address, website for model (if applicable)
- References to papers or other information about how the model should be cited
- Do you grant permission for results of the analysis using your model output to be archived at the MAST-DC website?: yes/no
- Does your model explicitly represent the following processes?
    - If yes, select all that are appropriate including Gross Primary Productivity, Heterotrophic Respiration, Autotrophic Respiration, Ecosystem

Respiration, Net Primary Production (and method of calculation), Net Ecosystem Exchange, Total Evapotranspiration, Soil Moisture

- Does your model explicitly represent model C pools?
    - If yes, select all that are appropriate from the following list: biomass C, litter C, soil organic C, soil inorganic C, other
- Does your model implicitly represent C pools
    - If yes, select all that are appropriate from the following list: biomass C, litter C, soil organic C, soil inorganic C, other
- Are you modeling land use and land use change? If so, which land uses are included in your model assessment (if applicable)? Possibilities include cropland, forestland, grassland, wetland, and settlements. What is the source of area data statistics for land use: e.g., NLCD, USDA-NASS, FIA, NRI, MODIS-Land Cover
- Which uncertainties did you address, including model input, model structure, parameter, measurement errors (if measurements are used in analysis), other

Optional information includes:

- Spatial and temporal scale information, on which the data were originally generated from the model (Note: file submission must be at scale listed in submission details above to be included in the analysis)
- Additional model information about soil and biomass C stock/pools (number of pools, dynamic or static representation), canopy leaf biomass modeled, details about soil hydrology model, representation of disturbances, testing/calibration of the model with USDA-NASS yield data, and testing/calibration/assimilation of data from MCI flux sites.
- Information about input data, including precipitation, temperature, humidity, wind speed, solar radiation, NDVI, EVI, LAI, fPAR, vegetation data, soil data or other input data/parameters.

Posting Data: Data can be uploaded for analysis using the following ftp site - ftp://nacp.ornl.gov/synthesis/2008/upload/mci. In addition data can be directly uploaded from the meta-data tool.