Closing the Methane Budget for the US Corn Belt & Upper Midwest: An Overview of the GEM Study

Dylan B. Millet¹, Timothy J. Griffis¹, John M. Baker¹, Stephen A. Conley², M. Julian Deventer¹, Alfredo DiCostanzo¹, Daven K. Henze³, Randall K. Kolka⁴, Eric A. Kort⁵, Xiang Li¹, Ashish Singh¹, Kelley C. Wells¹, Jeffrey D. Wood⁶, and Xueying Yu¹

¹University of Minnesota; ²Scientific Aviation; ³University of Colorado; ⁴US Forest Service; ⁵University of Michigan; ⁶University of Missouri

2019 NASA Terrestrial Ecology Science Team Meeting

Funding: NASA IDS
The Corn Belt & Upper Midwest: Key Component of the US Methane Budget

Major agricultural emissions

GEPA enteric + manure emissions

- 700 million livestock
- 28 million cattle
- IA + MN: ~75% of national hog production
- ~35% of NA livestock CH₄ flux based on current inventories

Also: among most wetland-rich areas in US

WetCHARTS wetland emissions

- Region: ~30% of NA wetland CH₄ flux

But: uncertainties are large

SD of WetCHARTS ensemble (same scale)

Large bottom-up vs. top-down discrepancies

[Maasakkers et al., 2016]

[Log scale]

[Maasakkers et al., 2016]

[0 24 48 72 96 120 × 10⁻¹¹ kg/m²/s]

[0.02 0.10 0.50 2.0 10.0 × 10⁻¹¹ kg/m²/s]
GEM Study: Targeted Uncertainties

**Wetlands.** The largest North American CH$_4$ source, but large divergence between estimates.

**Rivers and Streams.** Have shown elevated CH$_4$ (and N$_2$O) emissions in agricultural regions, but not well quantified into bottom-up inventories.

**Agriculture.** Bottom-up inventories uncertain due to sparse measurements, poor information on contribution from different sources, complicated site-specific management factors.

**Scaling.** Highly heterogeneous, discontinuous CH$_4$ sources, scaling challenges. Can we reconcile bottom-up process information with top-down constraints?
GEM: Multi-Scale Approach to Regional CH$_4$ Budget & Its National Context

- **Process-Scale**: Quantifying river/stream and agricultural facility emissions
- **Ecosystem-Scale**: Multi-year eddy flux measurements over wetlands
- **Regional-Scale**: Aircraft and tall-tower measurements, forward & inverse modeling (GEOS-Chem)
- **Scaling Up, National Context**: Satellite data analysis, modeling
Role of Rivers and Stream in CH$_4$ Budget

Science Questions:

What is the role of streams & river CH$_4$ emissions in agricultural landscapes?
→ Stream emissions found to double agricultural N$_2$O budget for the region [Turner et al., 2015]

What are the underlying controls on this flux and its variability?
→ N$_2$O emissions scale with stream order; are there emergent relationships for CH$_4$ that can be used for scaling?

Approach: In-situ measurements through an agricultural watershed

Cannon River Catchment
Lies in the agricultural Corn Belt of US Midwest
~1500 mi$^2$ in S. MN
Well-characterized during past N$_2$O work

Chamber deployment at Stream Order 1

Chamber deployment at Stream Order 7 (Minnesota River)

[Singh et al., in prep]
Role of Rivers and Stream in CH$_4$ Budget

Lead: Ashish Singh

**Intensive measurements**
- Chamber observations for dissolved, headspace & flux measurements of CH$_4$, CO$_2$, N$_2$O
- Detailed ancillary observations

**Extensive measurements**
- Dissolved & air concentrations of CH$_4$, CO$_2$, N$_2$O
- Subset of ancillary observations

- Quantify flux & gas transfer velocities
- Characterize flux dependence on stream properties

**Derived scaling relationships, assess regional budget**

Ongoing measurements!

Initial results point to:

- Large, highly variable CH$_4$ fluxes
- No clear link to stream order (contrasts with N$_2$O, CO$_2$)
- Seasonality differs from N$_2$O, CO$_2$

[Singh et al., in prep]
Agricultural Emissions: Scaling Up

Leads: Xiang Li, Ashish Singh

Science Question:
How accurately do current bottom-up methods scale-up to quantify the importance of agricultural CH₄ emissions?

Approach:
Facility-level flux measurements to test bottom-up methodology.

Method 1: Tracer-Release

Use CH₄:tracer relationship to compute facility-level flux, compare with bottom-up prediction.

\[ F_{\text{CH}_4} = \text{unknown} \]

\[ F_{\text{N}_2\text{O}} = \text{tracer} \]
Agricultural Emissions: Scaling Up

**Method 2: Airborne quantification**

*Airborne facility-level flux measurements for:*

9 of largest CAFOs in region (dairies, beef, swine)

>100,000 animals combined

Multiple re-visits across seasons

-- Yu et al., in review --

Example finding:

Airborne + tracer release results support bottom-up enteric flux estimates

Large gap for manure emissions

→ management factors affecting emissions that are not well-captured in inventories

Space-time distribution of ag emissions mis-represented

Implications for source attribution, inverse modeling
Constraints on Wetland Fluxes From Eddy Covariance Measurements

Bog Lake Fen

Lead: Julian Deventer
Constraints on Wetland Fluxes From Eddy Covariance Measurements

Lead: Julian Deventer

Quantifying uncertainties in wetland CH$_4$ budgets

Multi-year flux measurements with independent instruments for error quantification

[Deventer et al., 2019]

Large interannual variability in emissions

Argues for strong climate sensitivity

Consecutive years can vary to 2x

Inter-annual flux variability much greater than in soil $T$
Constraints on Wetland Fluxes From Eddy Covariance Measurements

Example results: CH$_4$ flux dependence on interactions between T, hydrology, snow cover

Temperature Sensitivity (Q$_{10}$, mg/m$^2$K)

Higher Q10 in wetter years

Normalized Surface Water Input

Hysteresis: higher emissions, T-sensitivity in latter phase of year

Ongoing - testing current emission models:
Flux measurements versus WetCHARTs

Long-term flux data to evaluate modeled climate sensitivities for CH$_4$ emissions

WetCHARTs ensemble: comparable IAV to observations
Biased seasonality

[Deventer et al., 2019; Deventer et al. in prep]
Tall Tower Measurements to Quantify Regional CH$_4$ Flux Through Time

Lead: Tim Griffis

Example result - Seasonal inversions for 2016/17 show dominance of wetlands, ag CH$_4$ sources

[Chen et al., 2018]

Ongoing: Apply 4+ year dataset to quantify regional trends through time

[Griffis et al. in prep]

Concentration footprint: 75% within 600 km

Methane Flux (nmol/m$^2$/s)

06/16 09/16 12/17 03/17 06/17 09/17
Airborne Measurements Across Seasons to Derive Spatial Constraints

Leads: Dylan Millet, Eric Kort, Xueying Yu

Measurements span summer, winter, spring

Suite of trace gases: CH$_4$, CO$_2$, N$_2$O, CO, O$_3$, H$_2$O

Regional surveying for wetland, agriculture, urban emissions, point sources

Ongoing: inverse analysis of CH$_4$ and N$_2$O emissions
Multiple Inversion Frameworks to Quantify Midwest Methane Fluxes

Lead: Xueying Yu

1) High-resolution adjoint optimization (GEOS-Chem @ 0.25° × 0.3125°)

2) Sector-based analytical inversions for source attribution

3) Gaussian Mixture Model (GMM) to spatially cluster grid cells prior to optimization.

Example finding:
Bottom-up overestimate of springtime wetland CH₄ flux
Robust across inverse frameworks
Consistent with GEM eddy flux measurements

Exploit combined constraints from GEM, ACT-America, ATom
Next Steps:

Application of new TROPOMI CH$_4$ data
Retrieval evaluation
Assess consistency with constraints from GEM datasets; place regional findings in broader context

Lead: Xueying Yu