Estimating North American methane emissions with high spatial resolution using GOSAT

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Methods of estimating methane emissions

**Bottom-up**

- Cattle Density
- Global map of cattle emissions

**Top-down**

- Satellites provide dense spatial coverage but have large uncertainties

Forward Model

Inverse Model
Observing methane from low Earth orbit

Satellites Observing Methane:

- **Thermal IR**:
  - AIRS, TES, IASI, CrIS

- **Shortwave IR**:
  - SCIAMACHY
  - GOSAT
  - TROPOMI

- **GOSAT obs**: 06/2009 – 12/2011
GEOS-Chem compares well to observations.
Identifying a GOSAT/GEOS-Chem bias

- Model/satellite comparison identifies a high-latitude bias
  - Latitudinal bias not seen in surface, aircraft, or column comparison

- Remove bias before estimating methane emissions
  - Bias is either due to the model stratosphere or GOSAT retrievals

Observations are ready for inversion!
Balancing aggregation and smoothing error

Spatial correlations are important at fine spatial scales!

Optimal size must balance aggregation and smoothing error.

Posterior error depends on choice of state vector dimension.

Choose \( n = 369 \) for negligible aggregation error; allows analytical inversion with full error characterization.

Aggregation Matrix: \( \Gamma_\omega \)

\[
x_\omega = \Gamma_\omega x
\]
Radial Basis Functions retain high resolution

- Decompose the state vector into Gaussians
  - Group based on correlated prior emission patterns

- Retain high resolution
  - Coarsen weak or uniform signals
Prior methane emissions from EDGARv4.2 + LPJ

**Major Sources (Tg a⁻¹)**

- Wetlands
- Livestock
- Oil/Gas
- Landfills
- Coal

**Total: 63/537 Tg a⁻¹**

North America  Global
General inversion framework: 2009–2011 GOSAT data

Global inversion provides dynamic BCs for North America
Constraining North American methane sources

Prior Emissions (2009 – 2011 average)

Averaging Kernel Sensitivity

- Averaging kernel matrix indicates regions our inverse model is sensitive to
- 39 degrees of freedom for signal (DOFs) in our system

Total: 63.3 Tg a\(^{-1}\)

DOFs: 38.8

Total: 91.3 Tg a\(^{-1}\)

\(\Delta CH_4: +27.9 \ Tg \ a^{-1}\)
Constraining North American methane sources

- Underestimated North American methane emissions
- Large underestimate in regions dominated by Livestock + Oil/Gas emissions

Prior Emissions (2009 – 2011 average)

Total: 63.3 Tg a⁻¹

Averaging Kernel Sensitivity

DOFs: 38.8

Posterior Methane Emissions

Total: 91.3 Tg a⁻¹

Emission Scaling Factors (Posterior / Prior)

ΔCH₄: +27.9 Tg a⁻¹
Does this posterior inventory improve things?

- Consistent emission estimates with regional and local studies
  - Improves comparison with independent observations!

State of California
- EDGARv4.2
- This work
- Santoni et al., (2014)
- Wecht et al., (2014b)
- Wennberg et al., (2012)

SoCAB

Graph showing Observed Methane Concentration (ppbv) vs. GEOS-Chem Methane Concentration (ppbv) with prior and posterior predictions.

Prior
- $y = 661 + 0.64x$
- $y = 535 + 0.71x$

Posterior
- $y = 14 + 1.00x$
- $y = 147 + 0.92x$
US methane emissions and source attribution

- US emissions are a factor of 1.7 larger than the prior
- Livestock + Oil/Gas are the largest underestimated sources
- Attribution is sensitive to assumption about the prior error
Development of a gridded EPA methane inventory

Comparing EPA & EDGAR manure emissions

- **EPA CH$_4$ inventory:**
  - State-level emission factors
  - County-level livestock numbers
  - Further mapped to USDA livestock landtype maps
  - Includes a seasonal cycle

- **EDGAR v4.2FT CH$_4$ inventory:**
  - Based on national data
  - Mapped to grassland

Will facilitate comparison with the EPA methane emissions

Maasakkers et al., (in prep)
Conclusions

- Constraints from an inverse method can be optimized by balancing aggregation and smoothing errors
  - Enables analytical inversion with full error characterization

- GOSAT-derived methane emissions are a factor of 1.5 and 1.7 larger than US EPA and EDGARv4.2
  - Consistent with independent observations and focused studies

- Gridded EPA methane inventory under development
  - Will improve our prior info & source attribution (Maasakkers et al. in prep)

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