A synthesis of the global sources and sinks of methane over the past 3 decades, and implications for future monitoring

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Objectives

- Synthesize the available information on global CH4
- Derive a plausible scenario for its recent variability
  - Additional efforts within GeoCarbon
- Identify needs for future monitoring
The Tools and Data

**Atmospheric Observations**
- Ground-based data from observation networks (AGAGE, CSIRO, NOAA, UCI).
- Airborne observations.
- Satellite data.

**Emission Inventories**
- Agriculture and waste related emissions, fossil fuel emissions (EDGAR, EPA, IIASA).
- Fire emissions (GFED, GICC, FINN, RETRO).

**Biogeochemistry Models**
- Ensemble of different wetland models, (LPJ-WHyMe, LPJ-wsl, ORCHIDEE).
- Data and models to calculate annual flooded area.

**OH Sink**
- Long-term trends and decadal variability of the OH sink.
- ACCMIP CTMs intercomparison.

**Inverse Models**
- Suite of different atmospheric inversion models (TM5-4DVAR, LMDZ-MIOP, CarbonTracker-CH₄, GEOS-Chem, LMDZt-SACS, MATCH, TM2, GISS).
- TransCom intercomparison.
### Literature on Global Budgets

- Larger global emissions in B-U approaches than in T-D inversions because of larger natural emissions
- ~50 Tg global imbalance in B-U approaches. T-D constrained by atmosphere
- Large uncertainties remaining for some sources (min-max ranges)
- Increasing OH loss between decades in B-U (not clear in T-D)

<table>
<thead>
<tr>
<th>Source Type</th>
<th>1980-89</th>
<th>1990-99</th>
<th>2000-09</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Natural Sources</strong></td>
<td>Top-Down</td>
<td>Bottom-up</td>
<td>Top-Down</td>
</tr>
<tr>
<td>Geothermal (incl. oceans)</td>
<td>54 [32-76]</td>
<td>6 [7-0]</td>
<td>54 [32-76]</td>
</tr>
<tr>
<td>Hydrates</td>
<td>3 [0-1]</td>
<td>1 [0-1]</td>
<td>3 [0-1]</td>
</tr>
<tr>
<td>Permafrost (excl lakes &amp; wet)</td>
<td>1 [0-1]</td>
<td>1 [0-1]</td>
<td>1 [0-1]</td>
</tr>
<tr>
<td><strong>Atmospheric Growth Rate</strong></td>
<td>30 [16-40]</td>
<td>17</td>
<td>12</td>
</tr>
</tbody>
</table>

**Notes:**
- Natural emissions include sources and sinks.
- Anthropogenic emissions include sources and sinks.
- The table includes top-down and bottom-up estimates for each category.
- The min-max ranges are provided for each category to indicate uncertainties.
- No source or sink reaches the maximum level of confidence (large green circle)
- Robustness is larger in the 2000s than in previous decades
- Agreement can be degraded as more studies appear (e.g. BBG, wetlands, OH, ...)

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<tr>
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<tbody>
<tr>
<td>Natural Wetlands</td>
<td>T-D</td>
<td>B-U</td>
<td>T-D</td>
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<tr>
<td>Other Sources</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Agriculture and Waste</td>
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<tr>
<td>Biomass Burning</td>
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<tr>
<td>Fossil Fuels</td>
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<tr>
<td>OH Chemical Sink</td>
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</tbody>
</table>

Robustness (# studies):
- 1–3
- 4–6
- 7–9

Agreement (between studies):
- High (<33% difference)
- Medium (33–66% difference)
- Low (>66% difference)
Anthropogenic Sources

- Biomass Burning & Biofuels: 30-40 Tg/yr
- Domestic ruminants: 85-95 Tg/yr
- Rice cultivation: 30-40 Tg/yr
- Fossil fuels: 85-105 Tg/yr
- Waste decomposition: 65-90 Tg/yr
Natural Sources

- Wetlands: 140-280 Tg/yr
- Geological (incl. Oceans): 30-75 Tg/yr
- Hydrates: 1-10 Tg/yr
- Permafrost: 0-1 Tg/yr
- Termites: 2-20 Tg/yr
- Wildfires: 1-5 Tg/yr
- Wild animals: 15 Tg/yr
- Freshwaters: 10-70 Tg/yr

Budget 2000s by process
Methane Sinks

- Tropospheric chlorine: 15-40 Tg/yr
- Stratospheric chemistry: 15-85 Tg/yr
- Soil uptake: 10-45 Tg/yr
- Tropospheric OH: 450-620 Tg/yr
Range of global emissions (from atm. Obs & inversions)

Range of wetland emissions (B-U= light green, T-D = dark green)

5-year emission changes since 1985 for 3 categories
Range of global emissions can be matched with decreasing fugitive emissions.

**S0**: EDGAR/EPA + wetlands

**S1**: Decreasing fugitive emissions from 1985 to 2000 + EDGAR/EPA + wetlands (TD or BU)

5-year emission changes since 1985 for 3 categories
Range of global emissions can be matched with stable fossil and microbial emissions.

S0: EDGAR/EPA + wetlands
S1: Decreasing fugitive emissions from 1985 to 2000 + EDGAR/EPA + wetlands (TD or BU)
S2: Stable fossil and microbial between 1990 and 2005 + EDGAR/EPA + wetlands (TD or BU)

5-year emission changes since 1985 for 3 categories
Range of global emissions is less matched by stable fossil and decreasing microbial emissions.

**S0**: EDGAR/EPA + wetlands

**S1**: Decreasing fugitive emissions from 1985 to 2000 + EDGAR/EPA + wetlands (TD or BU)

**S2**: Stable fossil and microbial between 1990 and 2005 + EDGAR/EPA + wetlands (TD or BU)

**S3**: Decreasing microbial and stable fossil + EDGAR/EPA + wetlands (TD or BU)

5-year emission changes since 1985 for 3 categories
After 2005: Too fast increase for all scenarios!

S0: EDGAR/EPA + wetlands

S1: Decreasing fugitive emissions from 1985 to 2000 + EDGAR/EPA + wetlands (TD or BU)

S2: Stable fossil and microbial between 1990 and 2005 + EDGAR/EPA + wetlands (TD or BU)

S3: Decreasing microbial and stable fossil + EDGAR/EPA + wetlands (TD or BU)

5-year emission changes since 1985 for 3 categories
Scenario analysis: Summary

Stabilisation period (1999-2006):
→ Decreasing to stable fossil fuel emissions and stable to increasing microbial emissions are more likely

Resumed atmospheric increase (>2006):
→ Mix of fossil fuel and wetland emissions increase, but relative magnitude remains uncertain

GCP-CH4 WebSite
http://www.globalcarbonproject.org/methanebudget/
Do satellite measurements provide additional constraints?
SCIAMACHY inversions

NOAA flask network

SCIAMACHY

Frankenberg et al, 2010

Target period: 2003-2010
Mean 2003 – 2010:

After – Before 2007:

Error bars => Further improvements of the CH₄ observing system are needed!
Comparisons with LSCE & JRC

Mean 2003 – 2010:

After – Before 2007:
GOSAT CH$_4$ retrieval

2009 - present

RemoteC algorithm: Butz et al, GRL, 2011
Inverted fluxes: consistency between SCIA & GOSAT - differences compared with a priori fluxes -

G. Monteil et al, under review, JGR
Atmospheric inversions using different satellite datasets or surface observations

(d) Regional methane emissions for the best configurations of the study $TA_{0.6}^{0.125}$ (blue), $IA_{0.33}^{0.6}$ (green), $SU_{1}^{0.6}$ (violet) with error bars for posterior uncertainties

Cressot et al., submitted
Limitations & directions

• Satellite data coverage versus quality
  - Synergy TROPOMI / Merlin
  - Improved coverage high latitudes
  - In situ data are important!

• Sink optimization
  - Multiple tracer analysis
  - Increased vertical sensitivity
    (GeoCarbon => use of IASI data)
Limitations & Directions

• Quality of models
  - Transport modeling (=> Poster LSCE)
  - Wetland modeling (=> Poster SRON)

• Limited use of isotopes
  - InGOS FP7: high frequency measurements
  - Central calibration lab d^{13}C and dD
Summary

- Global budget: Sum of sources exceeds sum of sinks.
- Important role of fossil fuel in CH4 trends.
- Poorly constrained natural variability limits our ability to quantify ff trends.
  - Surface networks remain a crucial component
  - No effective use of data without better models