RECENT CHANGES OF CH$_4$ SINCE 2005
from FTIR observations and GEOS-CHEM simulation

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Methane changes

- Second anthropogenic greenhouse gas - $\text{GWP}_{100} = 28$ (IPCC-AR5)
- 1824 ppb: new high of +260% wrt pre-industrial levels (1750)
- ~1/5 of the increase in radiative forcing by human-linked greenhouse gases since 1750 is due to methane [Nisbet et al., 2014]
- Non monotonic behaviour
- Last 25 years...
  - Increase in the 90s
- The need "For a proper closure of the methane budget and the development of realistic future climate scenarios, methane emissions during this stabilization period should be understood and precisely quantified" Pison et al., 2013
- From 2005/2006: new increase → Why?
Methane changes

- Second anthropogenic greenhouse gas
- GWP 100 = 28
- 1824 ppb: new high of +260%
- ~1/5 of the increase in radiative forcing due to methane [Nisbet et al., 2014]
- Non monotonic behaviour
- Last 25 years...
  - Increase in the 90s
  - The need "For a proper closure of the methane budget and the development of realistic future climate scenarios methane emissions during this stabilization period should be understood and precisely quantified" Pison et al., 2013
NDACC Sites

1 Eureka (80°N, 86°W)
2 Jungfraujoch (46°N, 8°E)
3 Toronto (44°N, 79°W)
4 Tsukuba (36°N, 140°E)
5 Lauder (45°S, 169°E)
6 Arrival Heights (77°S, 166°E)
W. Bader - Recent changes of CH$_4$ after 2005 from FTIR observations and GEOS-CHEM simulation

**FTIR Observations - Total Columns**

Daily Mean Methane Total Columns in molecules/cm$^2$

**Eureka** (+0.32 ± 0.62 %/year)

**Jungfraujoch** (+0.18 ± 0.04 %/year)

**Toronto** (+0.34 ± 0.09 %/year)

**Tsukuba** (+0.36 ± 0.04 %/year)

**Lauder** (0.29 ± 0.04 %/year)

**Arrival Heights** (+0.26 ± 0.09 %/year)

CH$_4$ global increase from WMO/GAW global greenhouse gas monitoring network: 0.33%

Source attribution?
GEOS-CHEM tagged simulation

- **GEOS-CHEM model v9-02**
- **Chemical Transport Model**
- 2x2.5 & 47 vertical levels
- Time step: 3 hours
- GEOS5 (2005-2013/05)
- GFED3
- OH_v5-07-08
- EDGAR v4.2 (2004-2008)
- K. Wecht et al., 2014
- Each tracer represents the contribution of each source to the simulated total column of methane

<table>
<thead>
<tr>
<th>Tracers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - Total</td>
</tr>
<tr>
<td>2 - Gas and oil</td>
</tr>
<tr>
<td>3 - Coal</td>
</tr>
<tr>
<td>4 - Livestock</td>
</tr>
<tr>
<td>5 - Waste management</td>
</tr>
<tr>
<td>6 - Biofuels</td>
</tr>
<tr>
<td>7 - Rice cultures</td>
</tr>
<tr>
<td>8 - Biomass burning</td>
</tr>
<tr>
<td>9 - Wetlands</td>
</tr>
<tr>
<td>10 - Other natural</td>
</tr>
<tr>
<td>11 - Other anthropogenic</td>
</tr>
<tr>
<td>12 - Soil absorption</td>
</tr>
</tbody>
</table>
Nearest-neighbour interpolation to match ground-based instrument coordinates

Conservative regridding scheme to the grid used in the FTIR retrieval

Specific to each station

Smoothing of GEOS-CHEM data by the respective averaging kernels

Changes calculation with a bootstrap resampling method

Linear fit + Fourier series (Gardiner et al., 2008)

Mean annual change (in %/year)

Comparison only for days when observation is available
FTIR Observations vs GEOS-CHEM

Total Column
W. Bader - Recent changes of CH$_4$ after 2005 from FTIR observations and GEOS-CHEM simulation

FTIR Observations vs. GEOS-CHEM Simulation
Total Columns

Daily Mean Methane Total Columns in molecules/cm$^2$
Mean CH$_4$ changes in %/year

Eureka (+0.32 ± 0.10) & GC (+0.36 ± 0.06)

Jungfraujoch (+0.18 ± 0.04) & GC (+0.27 ± 0.03)

Toronto (+0.34 ± 0.09) & GC (+0.34 ± 0.03)

Tsukuba (+ 0.36 ± 0.04) & GC (+0.36 ± 0.03)

Lauder (+0.29 ± 0.04) & GC (0.35 ± 0.03)

Arrival Heights (+0.26 ± 0.09) & GC (+0.39 ± 0.05)
GEOS-CHEM known issues

- EDGAR emission inventory
  - Spatial patterns
  - Increase in Chinese CH$_4$ emissions from coal after 2002 not supported by surface aircraft or satellite observations
  - Best inventory available
- Simplistic stratosphere (first order-loss)
- Best version available so far
- How good is the GEOS-CHEM simulation vertically?
Recent changes of CH$_4$ after 2005 from FTIR observations and GEOS-CHEM simulation

DOFS = ~2.2 - Information content allows us to retrieve two partial columns

A tropospheric and a stratospheric one
FTIR Observations vs GEOS-CHEM
Stratospheric Column
FTIR vs GEOS-CHEM
Stratospheric Methane
Mean Annual Changes in %

FTIR Observations, ACE-FTS occultations and the GEOS-CHEM simulation are statistically in agreement.
FTIR vs GEOS-CHEM
Stratospheric Methane
Mean Annual Changes in %

TSU - GC and FTS are not in agreement
LAU - GC overestimates measurements
AHTS - ACE 10° band + polar vortex
FTIR Observations vs GEOS-CHEM

Tropospheric Column
W. Bader - Recent changes of CH$_4$ after 2005 from FTIR observations and GEOS-CHEM simulation

**FTIR Observations vs GEOS-CHEM Simulation**

**Tropospheric methane**

GEOS-CHEM tends to overestimate the tropospheric change but agrees within error bars for Eureka, Toronto and Lauder.

Jungfraujoch: high altitude site (3.58 km) problem with vertical gradient of GC CH$_4$

Arrival heights: Polar Vortex issue?
CH$_4$ total column changes are in the same order of magnitude than the tropospheric one as observed by FTS and simulated by GEOS-CHEM whereas stratospheric CH$_4$ show different type of regime from one station to another.
What does the taggued simulation tell us about the methane changes?
W. Bader - Recent changes of CH₄ after 2005 from FTIR observations and GEOS-CHEM simulation

GEOS-CHEM - Tracer Analysis
Tropospheric CH₄ - Jungfraujoch

Yearly relative changes from one year to another to illustrate how each tracer contributes to the total CH₄ increase simulated by GEOS-CHEM

PRELIMINARY not smoothed
W. Bader - Recent changes of CH₄ after 2005 from FTIR observations and GEOS-CHEM simulation

GEOS-CHEM - Tracer Analysis
Tropospheric CH₄ - Jungfraujoch

Coal mining contributes to 75% of the cumulative increase! (only 7% of budget of CH₄)

Cumulative increase of CH₄ in % since 2005

1  Coal Mining  0.85
2  Gas and oil  0.41
3  Rice  0.29
4  Wetlands  0.27
5  Livestock  0.24
6  Waste  0.16
7  Other Anthr.  0.049
8  Biofuels  0.047
9  Other Natural  -0.017
10  Biomass Burning  -0.148

sink Soil absorption  0.0541
W. Bader - Recent changes of CH$_4$ after 2005 from FTIR observations and GEOS-CHEM simulation

GEOS-CHEM - Tracer Analysis
Tropospheric CH$_4$ - Tsukuba

Coal : half of increase !
Gas and oil contributes to ~20% of the cumulative increase !

Cumulative increase of CH$_4$ in % since 2005

<table>
<thead>
<tr>
<th>Source</th>
<th>Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>1.72</td>
</tr>
<tr>
<td>Coal Mining</td>
<td>0.86</td>
</tr>
<tr>
<td>Gas and oil</td>
<td>0.39</td>
</tr>
<tr>
<td>Rice</td>
<td>0.24</td>
</tr>
<tr>
<td>Livestock</td>
<td>0.15</td>
</tr>
<tr>
<td>Waste</td>
<td>0.13</td>
</tr>
<tr>
<td>Other Anthr.</td>
<td>0.044</td>
</tr>
<tr>
<td>Wetlands</td>
<td>0.043</td>
</tr>
<tr>
<td>Biofuels</td>
<td>0.038</td>
</tr>
<tr>
<td>Other Natural</td>
<td>-0.029</td>
</tr>
<tr>
<td>Biomass Burning</td>
<td>-0.170</td>
</tr>
<tr>
<td>Soil absorption</td>
<td>0.059</td>
</tr>
</tbody>
</table>

sink Soil absorption
W. Bader - Recent changes of CH$_4$ after 2005 from FTIR observations and GEOS-CHEM simulation

**GEOS-CHEM - Tracer Analysis**

**Tropospheric CH$_4$ - Lauder**

Wetlands emission is the first contributor to the CH$_4$ increase with coal mining and livestock.

Cumulative increase of CH$_4$ in % since 2005

<table>
<thead>
<tr>
<th>Source</th>
<th>Increase (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>4.85</td>
</tr>
<tr>
<td>1 Wetlands</td>
<td>1.07</td>
</tr>
<tr>
<td>2 Coal Mining</td>
<td>1.02</td>
</tr>
<tr>
<td>3 Livestock</td>
<td>0.91</td>
</tr>
<tr>
<td>4 Gas and oil</td>
<td>0.77</td>
</tr>
<tr>
<td>5 Waste</td>
<td>0.51</td>
</tr>
<tr>
<td>6 Rice</td>
<td>0.49</td>
</tr>
<tr>
<td>7 Biofuels</td>
<td>0.12</td>
</tr>
<tr>
<td>8 Other Anthr.</td>
<td>0.089</td>
</tr>
<tr>
<td>9 Other Natural</td>
<td>0.050</td>
</tr>
<tr>
<td>10 Biomass Burning - sink</td>
<td>-0.079</td>
</tr>
</tbody>
</table>

**Total**

| Total | 4.85 |

**Source**

- Biomass Burning
- Biofuels
- Coal Mining
- Livestock
- Gas and oil
- Waste
- Wetlands
- Other Anthropogenic
- Other Natural
- Rice
- Other

**sink**

Soil absorption -0.061
### Ranking of CH$_4$ Tracers Contribution to the Increase (from Largest to Smallest Contribution)

<table>
<thead>
<tr>
<th>Eureka</th>
<th>Jungfraujoch</th>
<th>Toronto</th>
<th>Tsukuba</th>
<th>Lauder</th>
<th>Arrival Heights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal Mining</td>
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</tr>
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<td>Wetlands</td>
<td>Gas and oil</td>
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<tr>
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<td>Wetlands</td>
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<tr>
<td>Rice</td>
<td>Livestock</td>
<td>Rice</td>
<td>Waste</td>
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<tr>
<td>Waste</td>
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<td>Waste</td>
<td>Other Anthr.</td>
<td>Rice</td>
<td>Rice</td>
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<tr>
<td>Biofuels</td>
<td>Other Anthr.</td>
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<td>Wetlands</td>
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<tr>
<td>Other Nat.</td>
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<td>Biomass Burn</td>
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*PRELIMINARY*

W. Bader - Recent changes of CH$_4$ after 2005 from FTIR observations and GEOS-CHEM simulation
Conclusions & next steps…

- Comparisons between FTIR observations and GEOS-CHEM simulation shows a good agreement in terms of changes in CH$_4$ total column.
- Vertical differences of CH$_4$ changes between FTIR observations and GEOS-CHEM simulation have been characterised.
  - Stratospheric comparisons supported by ACE-FTS occultations.
  - Tropospheric changes $\approx$ Total columns changes.
- Preliminary tracer analysis shows a major contribution to the increase from coal mining and gas and oil exploitations.

- Build CH$_4$ a priori profiles for each tracer in order to smooth the tagged simulation.
- Site by site analysis of each tracer behaviour since 2005 and their contribution to the changes of methane.
Acknowledgments
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