Global methane emissions and impacts on climate, air quality, and vegetation

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CH$_4$ cycles in the atmosphere

- Main loss from reaction with OH in the atmosphere
  - 9.8 ± 1.6 yrs (Voulgarakis et al., 2013), 11.2±1.3 year (Prather et al., 2012)
  - Lifetime extended by increased CH$_4$ (e.g., Holmes et al., 2013)
  - Products include O$_3$
  - NO$_x$ reductions will decrease O$_3$ but also decrease OH, thereby increasing CH$_4$
### CH$_4$ emissions sources

**Sources 2000-2009**

(Kirschke et al., 2013)

<table>
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<th>Source</th>
<th>Tg CH$_4$ yr$^{-1}$</th>
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Top-down | Bottom up estimates (Kirschke et al., 2013)
### CH$_4$ emissions sources

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Observed CH$_4$ concentration trends

Kirschke et al., 2013:
- Increasing wetland and fossil fuel emissions?
- Decrease / stabilization of fossil fuel and stable / increasing microbial activity?

Nisbet et al., 2014
CH$_4$ emissions trends

RCP Emissions trends

Lamarque et al., 2010
Moss et al., 2010

http://tntcat.iiasa.ac.at:8787/RcpDb
© RCP Database (Version 2.0.5)
Modeled CH$_4$ concentration trends

Multi-model (ACCMIP) estimates of global CH$_4$ burden following historical and future RCPs (Young et al., 2013)

~1750 ppb

~800 ppb
Impacts of changes in CH$_4$ concentrations

Climate (radiative forcings from Myhre et al., 2013)
- direct RF (0.48 ±0.05 W/m$^2$)
- via CH$_4$ (0.14 W/m$^2$)

Air Quality
- via O$_3$
- and aerosols?

Ecosystems
- via O$_3$

Young et al., 2013
When and where does O$_3$ change owing to $\Delta$[CH$_4$]?

3D spatial distribution of O$_3$ response to $\Delta$[CH$_4$] is not uniform (e.g., Fiore et al., 2008; Morgenstern et al., 2013; Fang et al., 2013)

O$_3$ response to uniform $-20\% \Delta$[CH$_4$] reduction (Fiore et al., 2008).

3D spatial distribution important because not all O$_3$ is radiatively equivalent

Aug 2006, land, daytime
CH$_4$ and long-term O$_3$ Radiative Forcing: response to CH$_4$ emissions

RF of -20% $\Delta$[CH$_4$] from HTAP (Fry et al., 2012).

note: includes long-term impacts of CH$_4$ on O$_3$.
CH$_4$ and long-term O$_3$ Radiative Forcing: response to CH$_4$ emissions

RF of $-20\% \Delta[CH_4]$ from HTAP (Fry et al., 2012).
compare to $-20$ NO$_x$, NMVOC or CO

Methane buffers the climate benefits of NO$_x$ reductions and amplifies that of NMVOCs, CO.
When and where does \( O_3 \) change owing to \( \Delta[CH_4] \)?

Response of North American daily mean afternoon (1300-1700 local time) summertime surface \( O_3 \) (Fiore et al., 2002)

![Graph showing probability distribution of ozone concentration with different emission scenarios: BASE, -50% CH\(_4\) emissions, -50% NO\(_x\) emissions, and -50% both.]

West et al., 2005
When and where does $O_3$ change owing to $\Delta[CH_4]$?

Present – PreIndust surface $O_3$ (Fang et al., 2013)

Present $CH_4$ accounts for $\sim 5$ ppbv of surface $O_3$ (5-10 in NH, 2-5 in SH)

Population-weighted changes:
- + 25 ppb (emissions)
- + 0.5 ppb (climate)
- + 4.3 ppb (CH$_4$ abundance)
Health impacts from preindustrial to present $\Delta [\text{CH}_4]$ 

Deaths / 1000 km$^2$ (Fang et al., 2013):

- About 50,000 increase in annual respiratory deaths.

- Combined impacts of $\Delta$climate and $\Delta [\text{CH}_4]$ lead to 20% increase in respiratory mortality from $\text{O}_3$ in some regions (e.g., Australia)
Deaths / 1000 km² (Fang et al., 2013):

- About 50,000 increase in annual respiratory deaths.

- Regionally significant cardio health impacts of $\Delta[\text{CH}_4]$ via aerosols? Large compared to health impacts via respiratory, but small (<5%) of increase in cardiopulmonary deaths owing to $\Delta$emissions of aerosols and aerosol precursors.
Air quality, health, and climate impacts of CH$_4$ emissions controls in the next several decades

- 20% CH$_4$ reductions lead to 1 ppb reduction and reduce cardiopulmonary deaths by 17,000 (West et al., 2006; Anenberg et al., 2010).

- CH$_4$ mitigation measures could reduce surface O$_3$ by 3-4 ppb and respiratory deaths by 70,000 (Anenberg et al., 2012).

- Cost of CH$_4$ reduction measures are cost effective with air quality and climate benefits (e.g., West et al., 2012; UNEP 2011), although benefits of SLCP-only measures perhaps overestimated (e.g., Smith and Mizrahi, 2013).
Climate and health impacts of Short Lived Climate Pollutants (SLCPs)

SLCPs = $\text{CH}_4$, BC, OC, CO, VOCs, NO$_x$, SO$_2$, NH$_3$, (HFCs)

Ramanathan and Xu, PNAS, 2010;
Hu et al., Nature CC, 2013
Ramanathan and Carmichael, Nature Geo, 2008

UNEP 2011;
Shindell et al., Science, 2012
Also: Avery et al., 2013
Impacts of global CH$_4$ emissions on vegetative O$_3$ exposure in Western US following RCPs

RCP 2.6: Global CH$_4$ emissions reductions shifts attainment forward by a decade.

RCP 8.5: Global CH$_4$ emissions increases more than counteract domestic efforts.

Lapina et al., in revision for GRL
Considerations for CH$_4$ abatement strategies (adapted / updated from West et al., 2012)

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<tr>
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<th>NOx and NMVOCs</th>
<th>CH$_4$</th>
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<tr>
<td>Abatement cost?</td>
<td>high (least cost options exhausted)</td>
<td>low</td>
</tr>
<tr>
<td>O$_3$ reductions?</td>
<td>large</td>
<td>several ppb</td>
</tr>
<tr>
<td>Time scale?</td>
<td>hours / weeks</td>
<td>decade</td>
</tr>
<tr>
<td>Spatial scale?</td>
<td>local/regional</td>
<td>global (more in NOx saturated regions)</td>
</tr>
<tr>
<td>Impact on peak O$_3$?</td>
<td>strong</td>
<td>not preferentially</td>
</tr>
<tr>
<td>Climate impacts?</td>
<td>Small (from NOx)</td>
<td>large (w/O$_3$)</td>
</tr>
<tr>
<td>Health impacts of 10% reduction?</td>
<td>22,000 (via PM$_{2.5}$) + similar amount via O$_3$</td>
<td>17,000 deaths per year from O$_3$</td>
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<td>Co-benefits?</td>
<td>reduce PM$_{2.5}$, reactive nitrogen deposition, toxics</td>
<td>energy security, NMVOC reductions, crop and vegetation</td>
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Questions?
Methane (CH$_4$) sources
Impacts of global CH$_4$ reductions on vegetative O$_3$ exposure metrics

Avnery et al., 2013
Impacts of global CH$_4$ reductions on crops
When and where does $O_3$ change owing to $\Delta[CH_4]$?

HTAP multi-model mean change from $\Delta[CH_4]$ of -20%
Mean [-0.4 to -2.2]
std dev [0.1 to 0.8]

Change in surface-level daytime $O_3$ (M12) in June [ppb]

Kees Cuvelier, Michael Seltzer