Recent Increases in the Burden of Atmospheric CH$_4$: Implications for the Paris Agreement

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$[\text{CH}_4](t) = [\text{CH}_4]_{ss} - ([\text{CH}_4]_{ss} - [\text{CH}_4]_0)e^{-t/\tau}$

Fit 1984-2006: $\tau = 9.2$ yr

Abrupt shift in CH$_4$ budget

Pinatubo

BB + WLs
Potential Causes of Increased CH$_4$: Changes in [OH]?

- Two 2-box-model studies:
  - Rigby et al. 2017; Turner et al., 2017
- Using MC as proxy, both suggest decreasing trend in [OH]
- Both agree data are consistent with no trend in [OH]
- Detailed spatial and temporal information not used
- Neither suggests a mechanism for $\Delta$[OH]
- Not consistent with 3-D CTM calculations of [OH] (nor $^{14}$CO constraint for SH extra-tropics)
- $\Delta$[OH] can not explain $\delta^{13}$C(CH$_4$)
- Suggest $\delta^{13}$CH$_4$ provides only a weak constraint
Potential Causes of Increased CH₄: Changes in OH?

• Not consistent with 3-D CTMs (e.g., Nicely et al., JGR, 2018)

• $\Delta[\text{OH}] = -0.08\pm0.19\%$/decade (1985-2015)
  • Decreased [OH] from increased [CH₄] compensated by:
    • Changes in ↑H₂O, ↑[NOₓ], ↓column O₃, tropical expansion, ↑T

• Biases in box model (e.g., Naus et al., ACP, 2019)

• Investigated systematic biases in transport and OH distribution in box models using 3-D CTM:
  • Accounting for biases reverses trend in [OH], making it positive:
    • Interhemispheric exchange rate
    • N/S asymmetry in [OH] (and “species-dependent” globally-averaged OH)
    • Stratospheric loss
    • Network bias in IHD (as in Pandey et al., 2019)
Globally averaged CH$_4$ and $\delta^{13}$C(CH$_4$)
Is $\delta^{13}\text{CH}_4$ a weak constraint?
*Although wide range of values observed, emission-weighted mean well-defined.

Larger uncertainty may be with Cl
*Small impact on atmospheric $X\text{CH}_4$
*$k^{12}\text{C}/k^{13}\text{C} \sim 1.066$
What does $\delta^{13}$C tell us?

• Schaefer et al., Nature, 2016
  • Increased microbial emissions outside Arctic
  • More likely agricultural sources than wetlands

• Nisbet et al., GBC, 2016; 2019
  • Increased microbial emissions in tropics
  • Wetlands and agricultural sources could contribute
    • Role for meteorology
    • Unlikely that changing lifetime contributed

• Thompson et al., GRL, 2018:
  • $\uparrow$ microbial ($36 \pm 12$) and FF ($15 \pm 8$ CH$_4$ Tg yr$^{-1}$)
  • Offset by BB (-3 ± 2) and soil sink (+5 ± 6 Tg CH$_4$ yr$^{-1}$)
  • No change in atmospheric sink
Does CH₄ threaten target of warming below 1.5°C?

Recent global average CH₄ mixing ratio relative to three scenarios used in the last IPCC assessment report.

Observed changes in radiative forcing for CO₂, CH₄ and N₂O relative to the RCP2.6 scenario.
Summary: Can we Explain the Observations?

• Understanding small changes to global budget is challenging
  • CH$_4$ budget is complex: many sources and sinks, all uncertain
  • Problem poorly constrained by observations
  • Increase over past decade likely caused by combination of multiple processes

• Should not ignore temporal and spatial information
  • Observed changes are abrupt and significant; points to role for wetlands

• Suspect that wetlands are involved and process models are not realistic
  • Fail to account properly for IAV in WL area and “memory effects”

• $\delta^{13}$C(CH$_4$) observations are certainly useful and perhaps misunderstood
  • Need better understanding of big levers: Cl and biomass burning
  • $\delta D$(CH$_4$) currently too few to be useful

• Recent increase in CH$_4$ burden hinders attainment of $\Delta T \leq 1.5 ^\circ C$
  • Increases need for costly and difficult carbon capture
Extra Slides
Climate impacts of increasing CH$_4$:  
* RCP 2.6 could achieve 1.5°C target  
* Already deviating from this trajectory for CH$_4$  
* Without CH$_4$ reductions, need CO$_2$ removal  
* Ignores SW component of RF (+25%)  
* Policy: natural or anthropogenic processes?
Annual mean column-integrated loss for CH$_4$ oxidation by OH and Cl:

- Cl + CH$_4$: 12-13 Tg CH$_4$ yr$^{-1}$ (2.5%)
- Contribution of Cl loss greatest at northern mid-latitudes
- Allan et al. (2007): 13-37 Tg CH$_4$ yr$^{-1}$
- Platt et al. (2004): up to 19 Tg CH$_4$ yr$^{-1}$

Sources of tropospheric Cl:

- Oxidation of natural and anthropogenic halocarbons (CH$_3$Cl, CHCl$_3$, etc.)
- Heterogeneous reactions involving sea salt

Hossaini et al., 2016

Cl + CH$_4$ (Small contribution to total sink):

- Large influence on $\delta^{13}$C(CH$_4$) with $(k^{12C/13C}) \approx 1.06$ or 60‰ fractionation
- Distribution: Hossaini et al., 2016

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IPCC SR15: Simple Summary

• Climate change is happening
  • 1°C warming so far
  • Increased extreme weather
  • Rising sea level

• It is happening faster than we expected
  • Disappearing Arctic sea ice

• We are running out of time to limit its larger impacts
  • Zero CO₂ emissions by 2050!
  • Technological change must be guided by policy
Role of Cl (Not just important in the stratosphere...)

- Cl + CH$_4$: Small contribution to total sink despite larger $k$ than for OH
  - Large influence on $\delta^{13}$C(CH$_4$) ($k(^{12}$C/$^{13}$C)$\approx$1.06)
- Allan et al., 2001
  - Evidence of role of Cl in observed $\delta^{13}$C(CH$_4$) at ~40°S

- Cl magnitude and distribution not well constrained
  - Allan et al., 2007: assumed photochemical from sea salt; guessed distribution
  - Hossaini et al., 2016: calculated magnitude and distribution with CTM
Variability in Atmospheric Methane From Fossil Fuel and Microbial Sources Over the Last Three Decades, R. L. Thompson et al., GRL, 2018

Optimized CH$_4$, C$_2$H$_6$, and $\delta^{13}$C(CH$_4$); from 2006-14:
* ↑microbial (36 ± 12) and FF (15 ± 8 CH$_4$ Tg yr$^{-1}$)
* Offset by BB (-3 ± 2) and soil sink (+5 ± 6 Tg CH$_4$ yr$^{-1}$)
* No change in atmospheric sink

Important details:
* 2-D model (12-boxes, 4 x lat, 3 x vert)
* Used only Allan Cl distribution
* Used constant CH$_4$/C$_2$H$_6$ emission ratio
Nisbet et al., 2018, in review:

Emissions (black/gray):
* Emissions increase by ~40 Tg CH$_4$ yr$^{-1}$ globally
* Avg $\delta^{13}$C of src gets lighter (30-90°N and 0-30°S)

Sinks (green):
* Large $\Delta$sink (±5% x [OH]) to explain observations
* Difficult to reconcile with short-term variability
"Emissions" = $d[\text{CH}_4]/dt + [\text{CH}_4]/\tau$

Trend (1984-2006) = $0.0 \pm 0.3 \text{Tg CH}_4 \text{yr}^{-1}$
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Hossaini et al., 2016
$\delta^{13}$CH$_4$ normalized to 2002:

* 3-D CTM with [OH] reduced 8% and constant CH$_4$ emissions
* The influence of sink fractionation on atmospheric $\delta^{13}$CH$_4$ is determined not only by [OH], but the weighted averages of OH, Cl, O(^1D), and soil sinks.
The $\delta^{13}C$-CH$_4$ Constraint:

- Before Chemistry: $\delta^{13}C$ = -53.6‰
- Observed Atmospheric: $\delta^{13}C$ = -47.3‰

Sherwood et al., 2017