Global Methane Budget

2020

The Global Methane budget for 2000-2017
Acknowledgements

The work presented here has been possible thanks to the enormous observational and modeling efforts of the institutions and networks below. Full references provided in Saunois et al. 2020, ESSD

**Atmospheric CH$_4$ datasets**
- NOAA/ESRL (Dlugokencky et al., 2011)
- AGAGE (Rigby et al., 2008)
- CSIRO (Francey et al., 1999)
- UCI (Simpson et al., 2012)

**Top-down atmospheric inversions**
- CarbonTracker-Europe CH$_4$ (Tsuruta et al., 2017)
- GELCA (Ishizawa et al., 2016)
- LMDz-SACS- PYVAR (Zheng et al., 2018a; 2018b; Yin et al., 2015)
- MIROC4-ACTM (Patra et al., 2016; 2018)
- NICAM-TM (Niwa et al., 2017b; 2017b)
- TM5-4DVAR (Houweling et al., 2014)
- NIES-TM- Flexpart (Maksyutov et al., 2020; Wang et al., 2019a)
- TM5-CAMS (Pandey et al., 2016; Segers and Houwelling, 2018)
- TM5-4DVAR (Bergamaschi et al., 2013; 2018)

**Bottom-up studies data and modeling**
- CLASS-CTEM (Arora et al. 2018; Melton and Arora, 2016)
- DLEM (Tian et al., 2010; 2015)
- ELM (Riley et al., 2011)
- JSBACH (Kleinen et al., 2019)
- JULES (Hayman et al., 2014)
- LPJ-GUESS (McGuire et al., 2012)
- LPJ-MPI (Kleinen et al., 2012)
- LPJ-wsl (Zhang et al., 2016)
- LPX-Bern (Spahni et al., 2011)
- ORCHIDEE (Ringeval et al., 2011)
- TEM-MDM (Zhuang et al., 2004)
- TRIPLEX-GHG (Zhu et al., 2104; 2015)
- VISIT (Ito ad Inatomi, 2012)
- FINNv1.5 (Wiedinmyer et al., 2011)
- GFASv1.3 (Kaiser et al., 2012)
- GFEDv4.1s (Giglio et al., 2013)
- QFEDv2.5 (Darmenov and da Silva, 2015)
- CEDS (Hoesly et al., 2018)
- IIASA GAINS ECLIPSEv6 (Högglund-Isaksson, 2012)
- EPA, 2012
- EDGARv4..3.2FT (Janssens-Maenhout et al. 2019)
- FAO (Tubiello et al., 2013; 2019)
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Increasing anthropogenic methane emissions arise equally from agricultural and fossil fuel sources

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Data access

- [Global Carbon Project](http://www.globalcarbonproject.org/methanebudget)
- [ICOS-CP](https://www.icos-cp.eu/GCP-CH4/2019)
Global Methane Budget Website
http://www.globalcarbonproject.org/methanebudget

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All data are shown in teragrams CH$_4$ (TgCH$_4$) for emissions and sinks, parts per billion (ppb) for atmospheric concentrations.

1 teragram (Tg) = 1 million tonnes = $1 \times 10^{12}$g
2.78 Tg CH$_4$ per ppb

Disclaimer

The Global Methane Budget and the information presented here are intended for those interested in learning about the carbon cycle, and how human activities are changing it. The information contained herein is provided as a public service, with the understanding that the Global Carbon Project team make no warranties, either expressed or implied, concerning the accuracy, completeness, reliability, or suitability of the information.
Context & Methods
The methane context

- After carbon dioxide (CO$_2$), methane (CH$_4$) is the most important greenhouse gas contributing to human-induced climate change.

- For a time horizon of 100 years, CH$_4$ has a Global Warming Potential 28 times larger than CO$_2$.

- Methane is responsible for 23% of the global warming produced by CO$_2$, CH$_4$ and N$_2$O.

- The concentration of CH$_4$ in the atmosphere is 150% above pre-industrial levels (cf. 1750).

- The atmospheric lifetime of CH$_4$ is 9±2 years, making it a good target for climate change mitigation.

- Methane also contributes to tropospheric production of ozone, a pollutant that harms human health, food production and ecosystems.

- Methane also leads to production of water vapor in the stratosphere by chemical reactions, enhancing global warming.

*Sources: Saunois et al. 2016, 2020, ESSD; IPCC 2013 5AR; Etminan et al. 2016*
An ensemble of tools and data to estimate the global methane budget

**Bottom-up budget**
- Atmospheric observations
- Emission inventories
- Biogeochemistry models & data-driven methods
- Methane sinks
- Inverse models

**Ground-based data from observation networks** (AGAGE, CSIRO, NOAA, UCI, LSCE, others).

**Satellite data** (GOSAT).

**Agriculture and waste related emissions**, fossil fuel emissions (EDGARv4.3.2, CEDS, USEPA, GAINS, FAO).

**Fire emissions** (GFED4s, FINN, GFAS, QFED, FAO).

**Biofuel estimates**

**Ensemble of 13 wetland models**
- Model for termites emissions
- Other sources from literature (inland water, geological, wild animal...)

**OH sink from CCMI experiment.**

**Soil uptake & chlorine sink taken from the literature**

**Suite of 9 atmospheric inversion models** (CTE-CH₄, GELCA, PYVAR-LMDz, MIRO4-ACTM, NICAM-TM, NIES-TM FLEXPART, TM5-CAMS, TM5-4DVAR-NIES, TOMCAT).

**Ensemble of 22 inversions (diff. obs & setup)**
CH$_4$ Atmospheric Growth Rate 2000-2017

- Slowdown of atmospheric growth rate before 2006
- Resumed increase after 2006

Source: Saunois et al. 2020, ESSD (Fig. 1)
The projections represented here correspond to RCPs defined for IPCC 5th Assessment Report.

- Methane concentrations rose faster in 2014, 2015 and 2019 with more than 10 ppb/yr.
- Since 2013, the atmospheric increase is approaching the warmest scenario of IPCC AR5 report.
Anthropogenic emissions:

• All inventories, except EPA, infer an increase in emissions as fast as the warmest scenarios between 2005 and 2017.

**Forcing target & scenario temperature range in 2100**
- Median temperatures using MAGICC (ECS=3°C)
  - Baseline (3.0–5.1°C)
  - 6.0W/m² (3.2–3.3°C)
  - 4.5W/m² (2.5–2.7°C)
  - 3.4W/m² (2.1–2.3°C)
  - 2.6W/m² (1.7–1.8°C)
  - 1.9W/m² (1.3–1.4°C)

The projections represented here correspond to SSPs defined for IPCC 6th Assessment Report.

**Source:** Saunois et al. 2020, ESSD (Fig. 2)
Atmospheric concentrations:

- Atmospheric observations (black line) fall between the estimates of the different scenarios

=> Monitoring of future years trends in emissions and concentration is critical to assess mitigation policy efficiency

The projections represented here correspond to SSPs defined for IPCC 6th Assessment Report

Forcing target & scenario temperature range in 2100
Median temperatures using MAGICC (ECS=3°C)
Baseline (3.0–5.1°C)
6.0W/m² (3.2–3.3°C)
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1.9W/m² (1.3–1.4°C)

Source: Saunois et al. 2020, ESSD (Fig. 2)
Decadal emissions & sinks
**Global Methane Budget 2017**

**TOTAL EMISSIONS**
- **Fossil fuel production and use**: 592 (572-614)
- **Agriculture and waste**: 227 (205-246)
- **Biomass and biofuel burning**: 28 (25-32)
- **Wetlands**: 194 (155-217)
- **Other natural emissions**: 39 (21-50)

**TOTAL SINKS**
- **Atmospheric CH4 growth rate**: +16.8% (14.0 to 19.5)
- **Sink from chemical reactions in the atmosphere**: 531 (502-540)
- **Sink in soils**: 40 (37-47)

Source: Jackson et al. 2020, ERL (Fig. 1)
Mapping of the largest methane source categories

Emission inventories

Biogeochemistry models & data-driven methods

Source: Saunois et al. 2020, ESSD (Fig 3);
• Wetlands are the largest natural global CH$_4$ source

• Vegetated wetland emissions are estimated using an ensemble of land-surface models constrained with remote-sensing based surface water and inventory based vegetated wetlands

• The resulting global flux range for natural wetland emissions is 102–182 TgCH$_4$/yr for the decade of 2008–2017, with an average of 149 TgCH$_4$/yr.
Mapping other natural sources

Other natural sources not mapped here are inland water emissions, permafrost and hydrates.

Source: Saunois et al. 2020 (Fig 4)
Methane Sinks (2000s)

- Tropospheric OH: 489-749 Tg/yr
- Stratospheric chemistry: 12-37 Tg/yr
- Soil uptake: 10-45 Tg/yr
- Tropospheric chlorine: 1-35 Tg/yr

Source: Saunois et al., 2020
Global Methane Emissions 2008-2017

**Bottom-up budget**

- Natural wetlands: 149 [50%]
- Agriculture & waste: 206 [15%]
- Fossil fuel: 128 [30%]
- Biomass/biofuel burning: 30 [30%]
- Other natural emissions: 222 [70%]

**Top-down budget**

- Natural wetlands: 181 [20%]
- Agriculture & waste: 217 [15%]
- Fossil fuel: 111 [50%]
- Biomass/biofuel burning: 30 [50%]
- Other natural emissions: 37 [80%]

**Mean [uncertainty = min-max range %]**

- Inland waters: 209 [70%]
- Geological: 45 [100%]
- Termites: 9 [100%]
- Oceans: 6 [100%]
- Wild animals: 2 [100%]
- Permafrost: 1 [100%]

- Coal: 42 [80%]
- Gas & oil: 80 [30%]
- Industry and transport: 7 [250%]

**Mean [min-max range %]**

- Rice: 30 [40%]
- Enteric ferm & manure: 111 [10%]
- Landfills & waste: 65 [15%]
- Coal: 42 [80%]
- Gas & oil: 80 [30%]
- Industry and transport: 7 [250%]

**Source:** Saunois et al. 2020, ESSD

**Bottom-up budget**

- Process models, inventories, data driven methods: 737 TgCH₄/yr [584-881]

**Top-down budget**

- Atmospheric inversions: 576 TgCH₄/yr [550-594]
Global emissions:
- 576 TgCH₄/yr [550-594] for TD
- 737 TgCH₄/yr [594-881] for BU

TD and BU estimates generally agree for agricultural emissions

Estimated fossil fuel emissions are lower for TD than for BU approaches

Estimated wetland emissions are higher for TD than for BU approaches

Large discrepancy between TD and BU estimates for freshwaters and natural geological sources (“other natural sources”)

Source: Saunois et al. 2020, ESSD (Fig 5)
Methane emissions by latitudinal bands 2008-2017

Source: Saunois et al. 2020, ESSD (Fig 7)

Contribution to global emissions

- Tropics (< 30°N)
- Mid-latitudes (30°N-60°N)
- Northern high latitudes (60°N-90°N)
64% of global methane emissions come mostly from tropical sources
Anthropogenic sources are responsible for about 60% of global emissions.
Largest emissions in South America, Africa, South-East Asia and China (50% of global emissions)
Dominance of wetland emissions in the tropics and boreal regions
Dominance of agriculture & waste in Asia
Balance between agriculture & waste and fossil fuels at mid-latitudes

Source: Jackson et al. 2020 ERL (Fig 2)
An interactive view of the methane budget

Source: Carbon Atlas
www.globalcarbonatlas.org
Emission changes
Changes in Methane Sources

- About 50 TgCH₄/yr emissions increase between 2000-2006 and 2017
- Increase mainly from the Tropics (about 30 TgCH₄/yr), followed by mid-latitudes (15-20 TgCH₄/yr)
- Regional contributions from Africa and Middle East, China and rest of Asia
- Increase in North America driven by the increase from USA
- Decrease in Europe

Source: Jackson et al. 2020 ERL (Fig 2)
Changes in Methane Sources

Emission changes between 2000-2006 and 2017

- Global increase mainly from anthropogenic sources equally between Agriculture and Waste and Fossil Fuel
- Fossil Fuel emissions increased in China, North America (USA), Africa, and Asia
- Agriculture and Waste emissions increased mostly in Africa, Southern Asia and South America
- Emissions decreased in Europe from both Fossil Fuel and Agriculture and Waste sources

Source: Jackson et al. 2020 ERL (Fig 2)
Sink changes
• Hydroxyl radical, OH is the main oxidant of CH$_4$, responsible of about 90% of methane removal in the atmosphere.

• Two approaches derive estimates of OH quantity in the atmosphere:
  1. Chemistry climate models that includes hundreds chemical reactions between numerous species
  2. Box-modeling based on methyl-chloroform (MCF) observations

• Both approaches derive a 10-15% uncertainty on global OH mean concentrations.

Source: Zhao et al. 2019

Source: Rigby et al. 2017
OH inter-annual variability and trend

- Chemistry climate models derive a null to positive trend in OH over 2000-2017
- MCF-based box modelling suggest a positive trend in OH over 1997-2005 followed by a negative trend from 2005 onward

⇒ High uncertainty remains on OH trend and interannual variability

Chemistry climate models

OH anomaly 2000–2010

MCF-based box modelling versus chemistry climate models

OH anomaly 1980-2015

Source: Zhao et al. 2019

Source: Ganesan et al. 2020
Methane emissions derived by top-down systems are dependent on the OH sink prescribed.

The range derived by an ensemble of top-down approaches in Saunois et al. (2020) is narrower than the one derived by a single top-down system when testing several OH distributions (from chemistry climate models).

The uncertainty in global total methane emissions is probably underestimated in Saunois et al. (2020).
Impact of OH change in the methane sink

- OH increase before 2007 could explain part of the stabilization of atmospheric methane.

- Stagnation or decrease in OH radicals can contribute to explain:
  - the renewed increase of atmospheric methane since 2007
  - The lighter atmosphere in $^{13}$C isotope since 2007

Source: Dalsoren et al., 2016
Since 2007: a sustained atmospheric CH$_4$ growth and $\delta^{13}$C-CH$_4$ decrease

- Need to understand which changes in emissions are responsible for both increasing atmospheric methane and decreasing $\delta^{13}$C-CH$_4$ since 2007

1867 ppb reached in 2019!

CH$_4$ Growth rates:

- 2014: $12.7\pm0.5$ ppb yr$^{-1}$
- 2015: $10.1\pm0.7$ ppb yr$^{-1}$
- 2016: $7.0\pm0.6$ ppb yr$^{-1}$
- 2017: $7.0\pm0.9$ ppb yr$^{-1}$
- 2018: $8.5\pm0.6$ ppb yr$^{-1}$
- 2019: $10.7\pm0.6$ ppb yr$^{-1}$

$\delta^{13}$C-CH$_4$ decreased by -0.2‰ in 10 years

Source: Nisbet et al., 2019
Highlights

- Atmospheric CH$_4$ concentrations are rising faster over the last decades than in the 2000s. Since 2013, the trend in atmospheric methane concentrations is closer to the most greenhouse-gas-intensive scenarios of IPCC AR5 than scenarios integrating mitigation policies.

- Anthropogenic sources are responsible for all or most of the recent rapid rise in global CH$_4$ concentrations, equally from agriculture and fossil fuels sources. Tropical regions play the most significant role as contributors to the atmospheric growth.

- The role of methane sinks has to be further explored as a slower destruction of methane by OH radicals in the atmosphere could have also contributed to the observed atmospheric changes of the past decade. However high uncertainties on OH burden and trend prevent any solid conclusions.

- Methane global emissions were 576 TgCH$_4$/yr [550-594] for 2008-2017 as inferred by an ensemble of atmospheric inversions (top-down approach) using an atmospheric constraint.

- Methane mitigation offers rapid climate benefits and economic, health and agricultural co-benefits that are highly complementary to CO$_2$ mitigation.

- Emission estimates from inventories/models (bottom-up approach) show larger global totals because of larger natural emissions. Improved emission inventories and estimates from inland water emissions are still needed.
Explore GHG emissions globally and by country and download data and illustrations. Also explore ‘Outreach’ and ‘Research’.

www.globalcarbonatlas.org
The methane budget, using data from Saunois 2020, can be visualized in 3D at: https://svs.gsfc.nasa.gov/4799
The work presented in the Global Methane Budget 2020 has been possible thanks to the contributions of hundreds of people involved in observational networks, modeling, and synthesis efforts. Not all of them are individually acknowledged in this presentation for reasons of space (see slide 3 for those individuals directly involved).

Additional acknowledgement is owed to those institutions and agencies that provide support for individuals and funding that enable the collaborative effort of bringing all components together in the carbon budget effort.

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<th>Title</th>
<th>Publication Details</th>
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