Attribution of the surge of global methane in 2020 using inverse analysis of GOSAT observations

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With Daniel J. Jacob, Yuzhong Zhang, Lu Shen, Xiao Lu, Tia R. Scarpelli, and Daniel Varon
CH$_4$ contributed to a 1.2 W m$^{-2}$ radiative forcing and 0.6°C increase of global mean surface air temperature.

Methane mitigation has the greatest potential to slow warming over the next 20 years. (IPCC AR6, 2021)
The Global Methane Pledge was formally launched on Nov 2.
More than 100 countries agree to cut methane emissions by 30% (0.2°C) by 2030.
Global burden is balanced by the sources and sinks

(Saunois et al., 2020)
Surge of CH$_4$ in 2020

Record high annual increase of 14.7 ppbv in 2020.

Unknown causes

- Increasing biogenic emissions
  *(Schaefer et al., 2016)*
- Increasing fossil fuel emissions
  *(Hausmann, 2016; Helmig et al., 2016)*
- Increasing wetlands & livestock
  *(Maasakkers et al., 2019)*
- Decreasing sink via OH
  *(Turner et al., 2017; Rigby et al., 2017)*
Surge of CH₄ in 2020

Global Methane Emissions Reach a Record High

The New York Times

Scientists expect emissions, driven by fossil fuels and agriculture, to continue rising rapidly.

Climate change: Greenhouse gas build-up reached new high in 2020

BBC News

Methane rises to highest level on record

The Guardian

Livestock farming and fossil fuels are main causes of rise in gas, which is 28 times more powerful than CO₂ at trapping heat

THE HILL

CO₂, methane emissions surged 2020 despite pandemic: NOAA
Decreasing NO$_x$ could decrease OH and the methane sink

**Sources**

CH$_4$ from oil and gas declined during COVID-19 in the US Permian Basin.

*(Lyon et al., 2021)*

Reduced maintenance in landfills and oil and gas infrastructure can lead to new leaks.

*(Laughner et al., 2021)*

**Sinks**

The maximum reduction of the tropospheric global mean OH occurs in May 2020, by 4%, can increase methane lifetime by 4 months.

*(Miyazaki et al., 2021)*
Generally consistent changes in $X_{\text{CH}_4}$ between TROPOMI and GOSAT

Column-averaged dry methane mixing ratios $X_{\text{CH}_4}$ (2020-2019)

Weaker increase/decrease in southeast China (rice).

Stronger increase in Northwest US, Europe, and wetland regions (DRC, South Sudan, and Alaska)
Use GOSAT observations to estimate emissions through inverse methods

**Top-down estimate**

predicted concentrations $\xrightarrow{\text{inversion}}$ observed concentrations

chemical transport model (GEOS-Chem)

correct bottom-up estimates (posterior)

bottom-up estimates (prior)
Inverse modeling of global methane sources and sinks

- GEOS-Chem v12.5.0, 2° × 2.5° resolution
- Whole year of 2019 & 2020
- EDGARv4.3.2 as global default; EPA greenhouse inventory for CONUS; oil, gas, and coal from GFEI; wetland from WetCHARTs
- Initial conditions on Jan 1, 2019 and Jan 1, 2020 are scaled to match GOSAT
- No correction on stratosphere – smaller biases at 2° × 2.5° & low latitudes

(Stanevich et al., 2019)
### Analytical inversion of the sources and sinks of methane

<table>
<thead>
<tr>
<th>Description</th>
<th>Variable</th>
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<tr>
<td>State vector</td>
<td>$\mathbf{x}$</td>
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<tr>
<td>Jacobian matrix</td>
<td>$\mathbf{K}$</td>
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<td>Satellite observation</td>
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<td>Observational error covariance matrix</td>
<td>$\mathbf{S_o}$</td>
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<td>Prior error covariance matrix</td>
<td>$\mathbf{S_a}$</td>
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**Cost Function** (Gaussian errors, uncorrelated obs & prior errors):

$$
J(x) = \frac{1}{2} (x - x_a)^T \mathbf{S_a}^{-1} (x - x_a) + \frac{1}{2} \gamma (y - Kx)^T \mathbf{S_o}^{-1} (y - Kx)
$$

**Regularization parameter** $\gamma = 0.5$ (L-curve test):

- accounts for the effect of error correlation not shown in $\mathbf{S_o}$

**Analytical solution:**

$$
\hat{x} = x_a + \left( \gamma \mathbf{K}^T \mathbf{S_o}^{-1} \mathbf{K} + \mathbf{S_a}^{-1} \right)^{-1} \gamma \mathbf{K}^T \mathbf{S_o}^{-1} (y - \mathbf{K}x)
$$
Global CH$_4$ imbalance increases by 71% from 2019 to 2020
Major changes in anthropogenic CH$_4$ emissions

Emission changes (2020-2019) [%]

- Brazil Livestock
- New Zealand Livestock
- China Coal
- China Rice
- India Rice

Oil & Gas
- Nigeria
- Uzbekistan
- Iran
- U.S.
Summary

• A global inversion of GOSAT methane observation shows a 71% increase of methane imbalance from 2019 to 2020, 29% of which are attributed to decreases in global OH concentrations.

• 71% of the increase in methane imbalance is attributed to increase in major anthropogenic sources, offset by reductions in rice and wetland emissions.