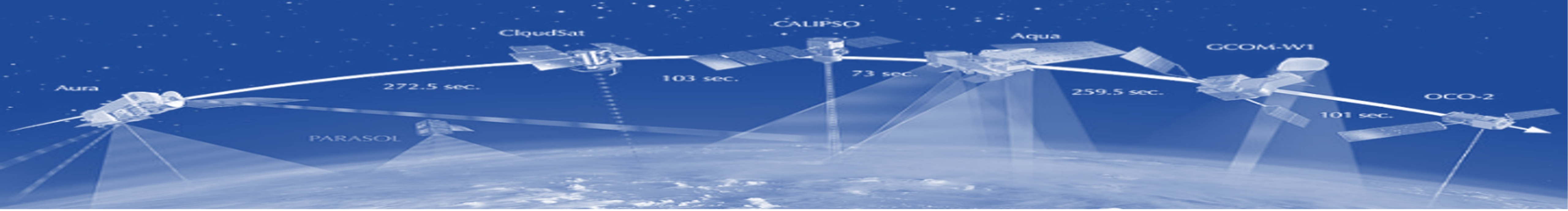

Attribution of the 2020 surge in atmospheric methane by inverse analysis of GOSAT observations

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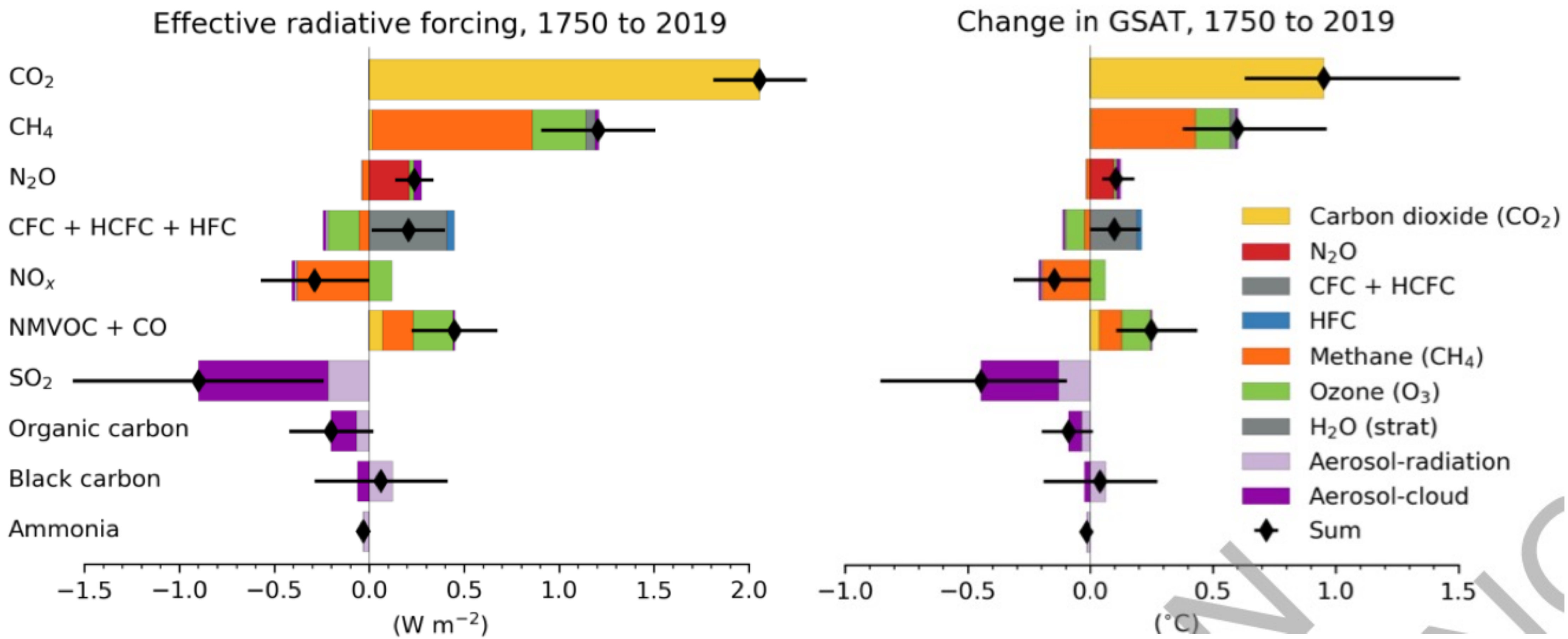
With Daniel J. Jacob, Yuzhong Zhang, Lu Shen, Daniel J. Varon, Xiao Lu, Tia R. Scarpelli, Anthony Bloom, John Worden, and Robert J. Parker

Climate Impacts of CH_4



- 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.

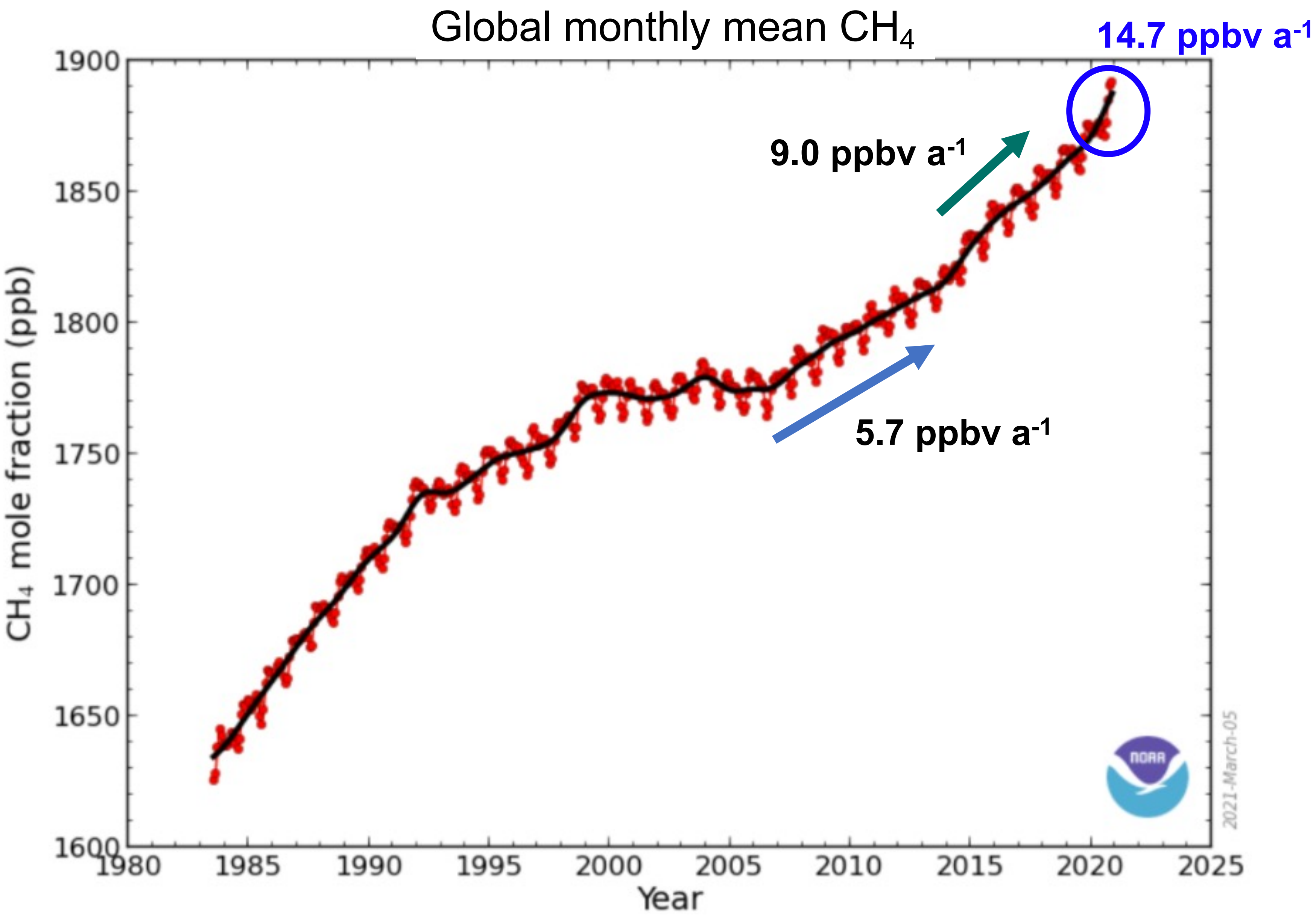
(*IPCC AR6,* 2021)

US and EU Announce Global Pledge to Slash CH_4

(Picture from USA Today)

- The Global Methane Pledge was formally launched on Nov 2, 2021.
- More than 100 countries agree to cut methane emissions by 30% (0.2°C) by 2030

Surge of CH_4 in 2020

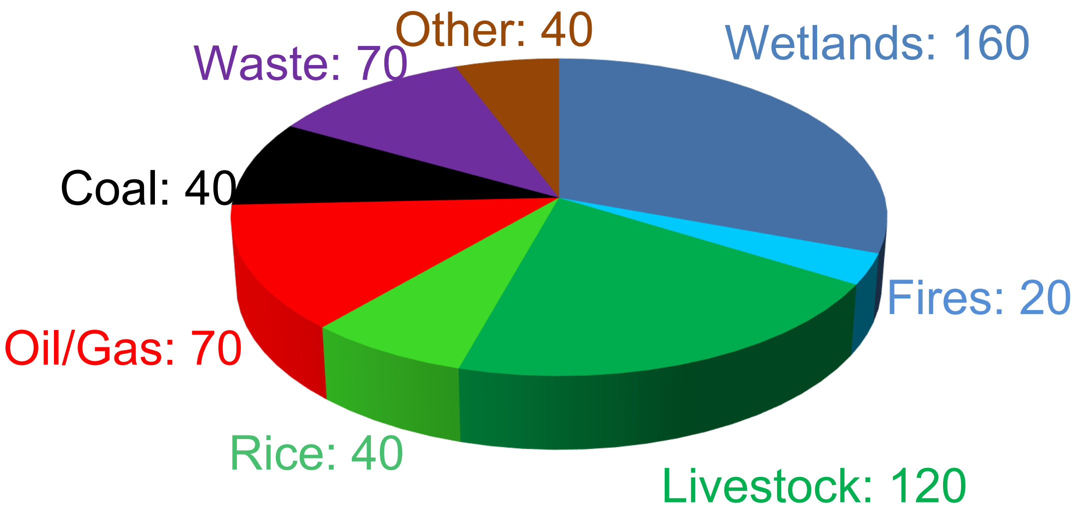


(*NOAA*, 2021)

Global CH_4 Burden is Balanced by the Sources and Sinks

Sources

Emission
560 ± 60 Tg a^{-1}



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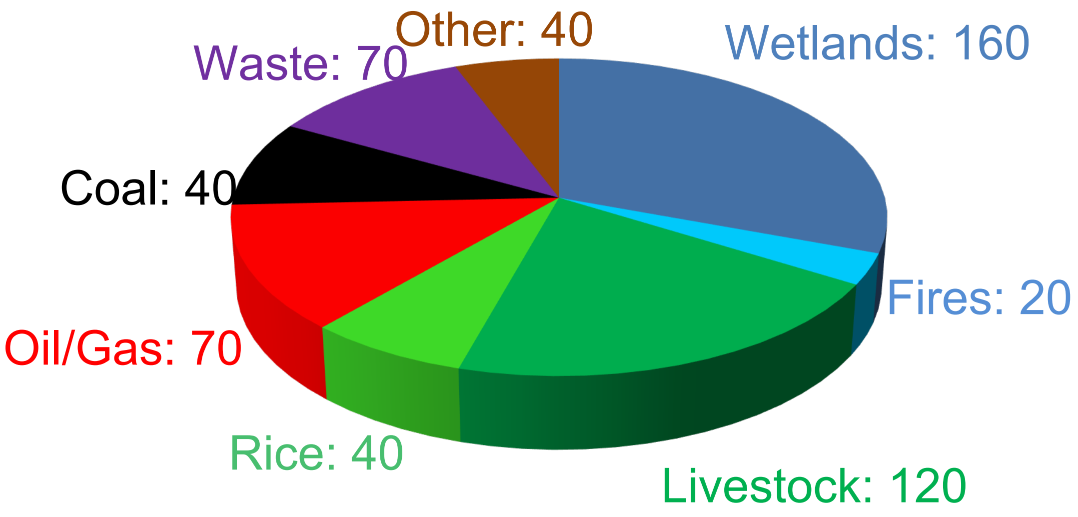

Sinks

Mainly through reactions with OH:

$$CH_4 + OH \longrightarrow CH_3 + H_2O$$

Sources – Sinks = Imbalance → Growth of CH_4 concentration

Changes in CH_4 Sources and Sinks During the COVID-19 Shutdown

Sources

(https://www.oilandgasiq.com/strategy-management-and-information/articles/oil-and-gas-companies)

- Oil and gas emission **declined** in the Permian Basin (*Laughner et al.*, 2021)
- Reduced maintenance lead to **new leaks** (*Lyon et al.*, 2021)

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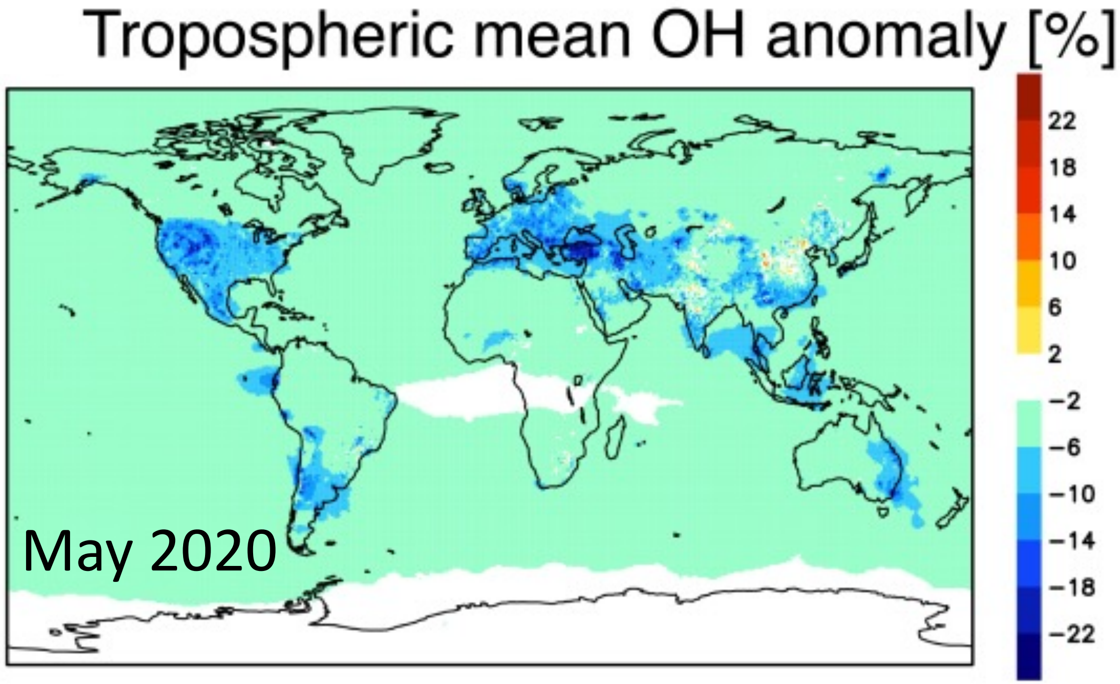
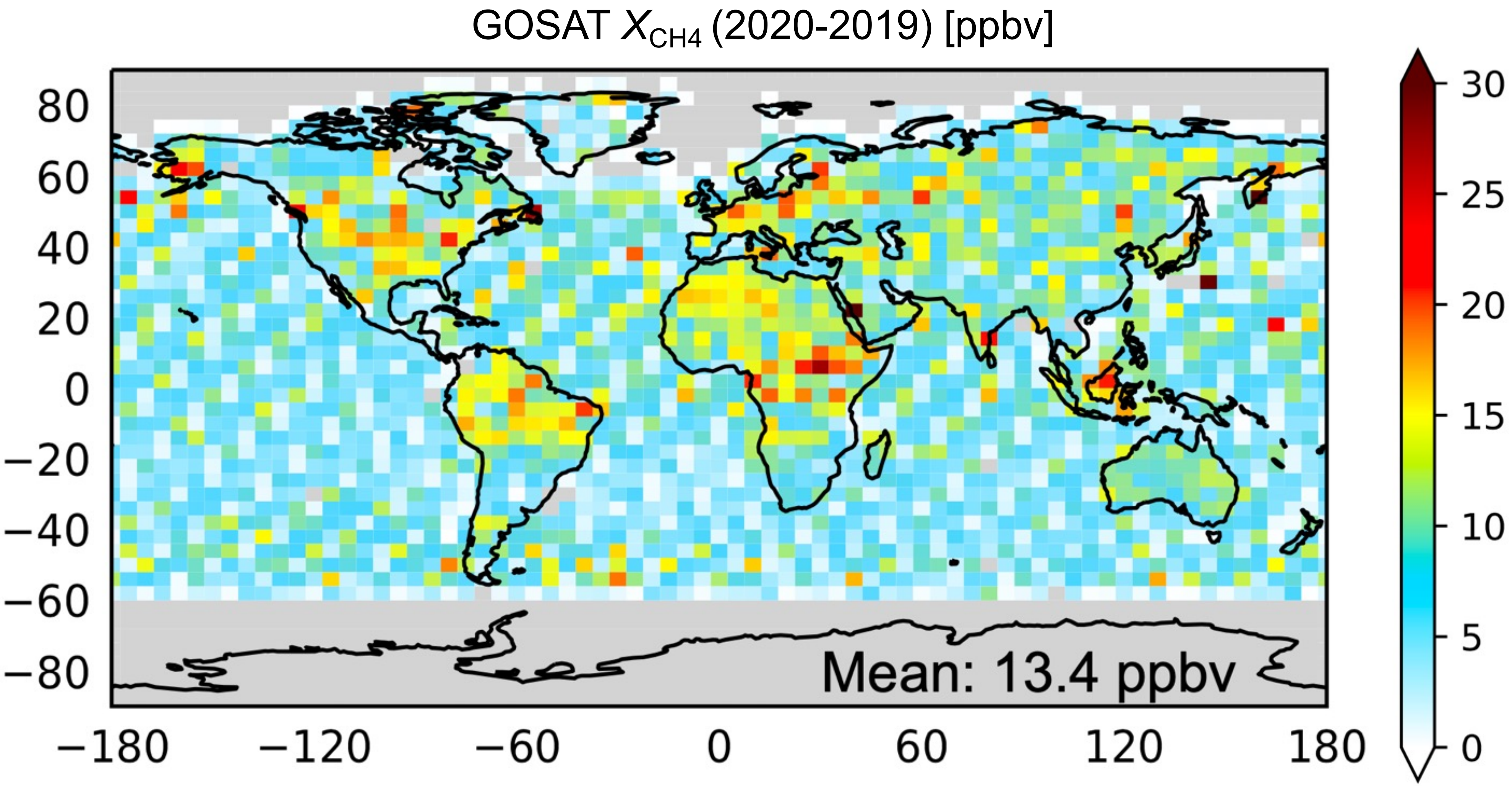


- Max reduction of 4% in global mean OH

(*Miyazaki et al.*, 2021)

Limitation: existing works do not quantify the relative impact of sources and sinks.

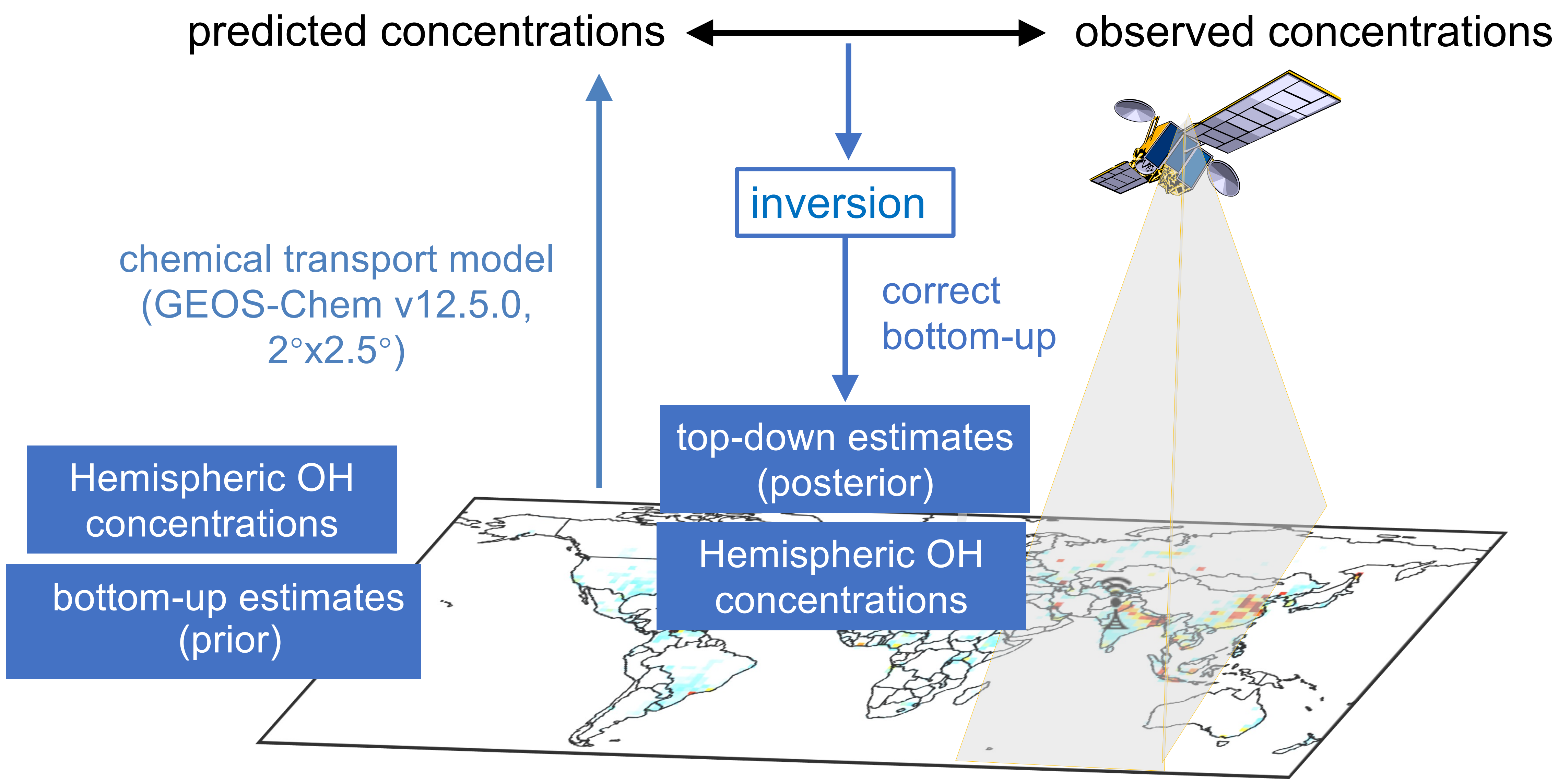
Global Averaged GOSAT CH_4 Increased by 13.4 ppbv from 2019 to 2020



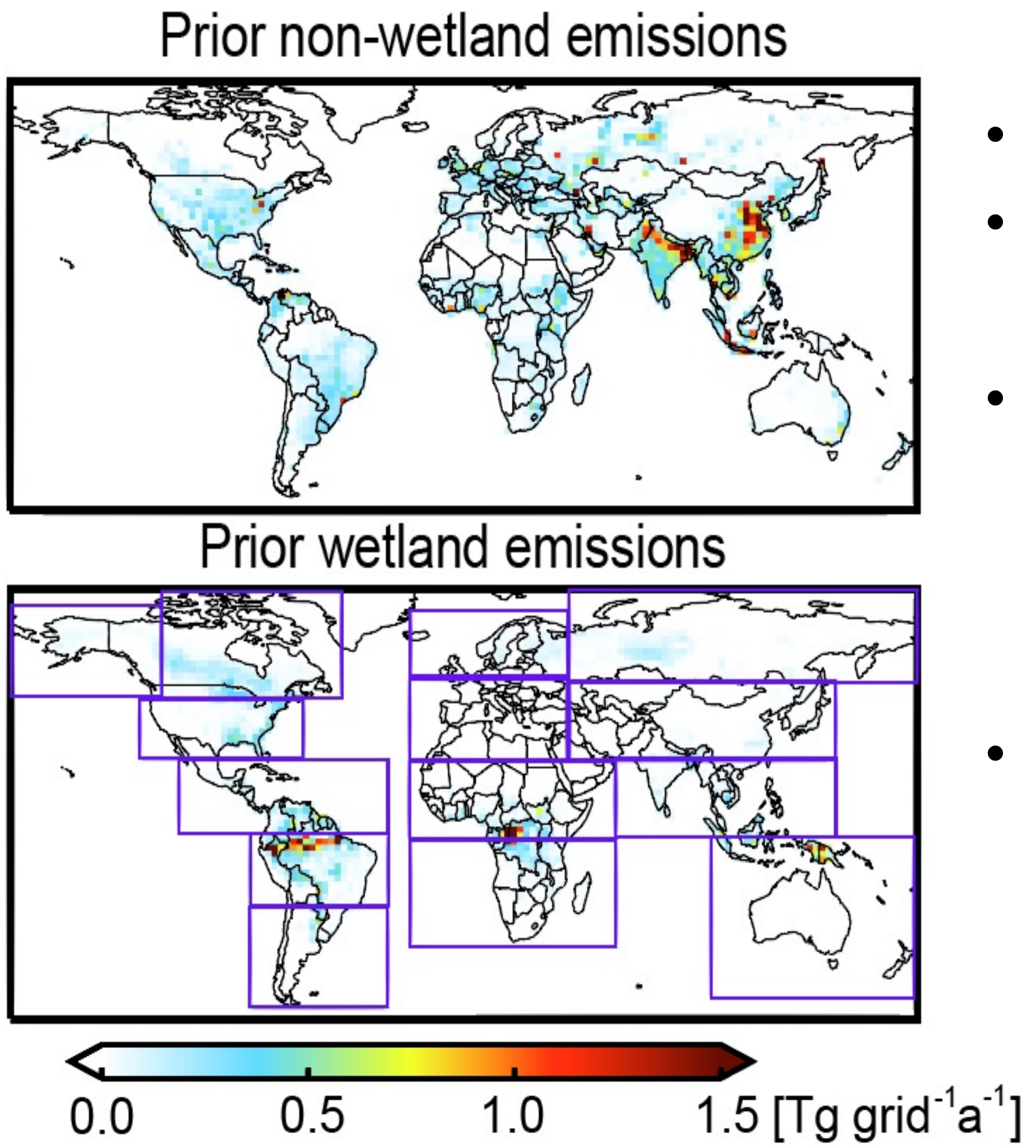
- Continental regions increased more than the oceans, arguing against a dominant role of the methane sink in driving the 2020 surge.

(*Qu et al.*, submitted)

Analytical Inversion of the Sources and Sinks of CH_4



Inverse Modeling of Global Methane Sources and Sinks



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

(Stanevich et al., 2019)

Optimizing CH_4 Sources and Sinks Using Observations

Methane growth rate: $\frac{dm}{dt} = E - km - L$

Acceleration of growth rate: $$\frac{d^2m}{dt^2} = \frac{dE}{dt} - k\frac{dm}{dt} - m\frac{dk}{dt} - \frac{dL}{dt}$$

Forcing away from steady state: $$F = \frac{dE}{dt} - m\frac{dk}{dt}$$

m = methane mass
E = emission
k = OH loss rate constant
L = minor losses (strat, Cl. Dep)

(*Qu et al.*, submitted)

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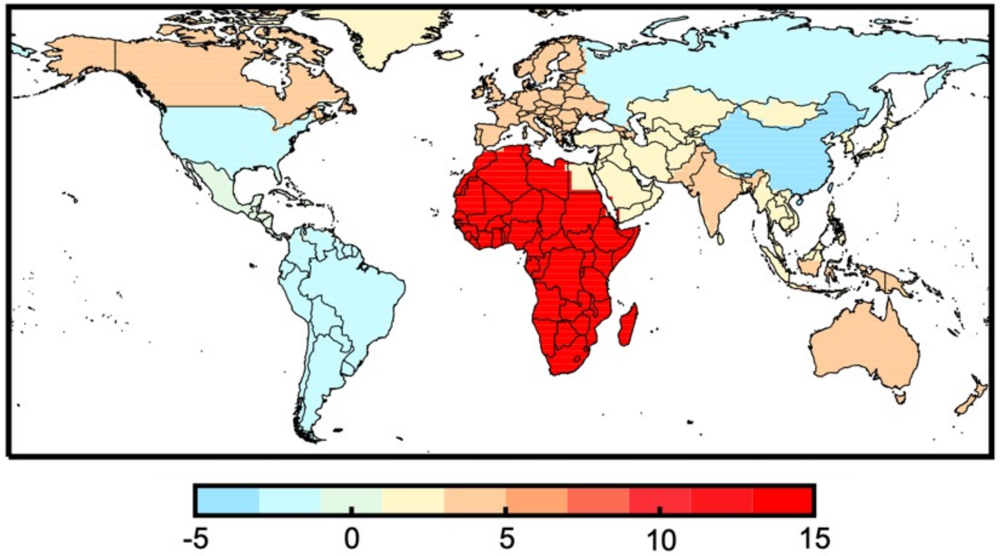
Sources + 31 Tg a^{-1} (86%)

2020-2019 change in emissions [Tg a^{-1}]



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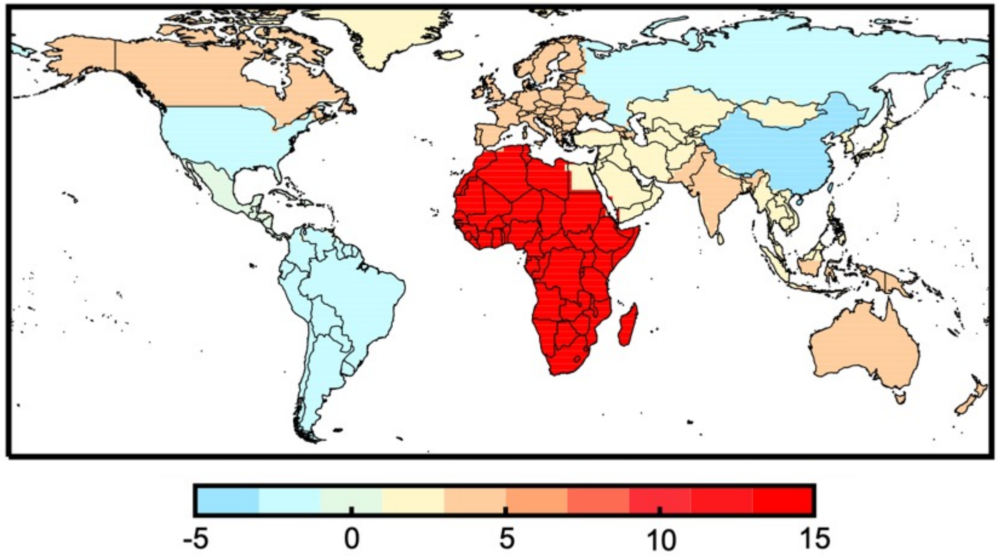
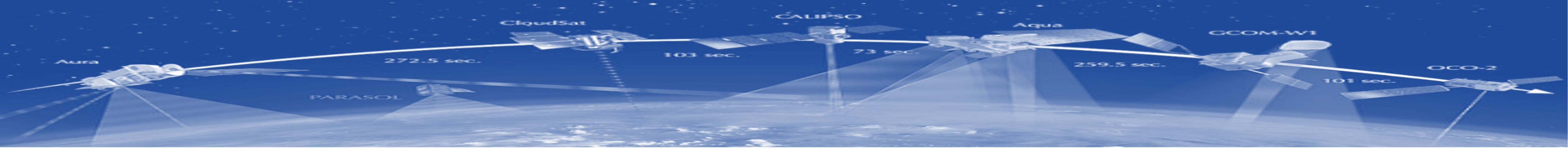


9-member inversion ensemble: + 30 ± 5.5 Tg a^{-1} (82% ± 18%)

Sinks - 5 Tg a^{-1} (14%)

Global mean OH reduce by 1.2%

(*Qu et al.*, submitted)



Summary

- A global inversion of GOSAT methane observation shows that:

- The increase of emissions contributes to 86% increase of forcing on methane budget away from a steady state, and the rest is attributed to decreases in global OH concentrations.

- Half of the increase in methane emissions from 2019 to 2020 is in Africa, potentially due to high precipitation and flooding in East Africa.

- We may be seeing the wetlands respond to climate change!

Analytical Inversion of the Sources and Sinks of CH_4

Description	Variable
State vector	$\mathbf{x}$
Jacobian matrix	$\mathbf{K}$
Satellite observation	$\mathbf{y}$
Observational error covariance matrix	$\mathbf{S_o}$
Prior error covariance matrix	$\mathbf{S_a}$
Regularization parameter	γ

Cost Function (Gaussian errors, uncorrelated obs & prior errors):

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

Analytical solution: $\hat{\boldsymbol{x}} = \boldsymbol{x}_a + \left(\gamma\mathbf{K}^T\mathbf{S_o}^{-1}\mathbf{K} + \mathbf{S_a}^{-1}\right)^{-1}\gamma\mathbf{K}^T\mathbf{S_o}^{-1}(\boldsymbol{y} - \mathbf{K}\mathbf{x})$