# Policy Implications of a Global Assessment of Oil and Gas Methane Ultra-Emitters

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With : C. Giron, T. Lauvaux, A. d'Aspremont and S. Peng

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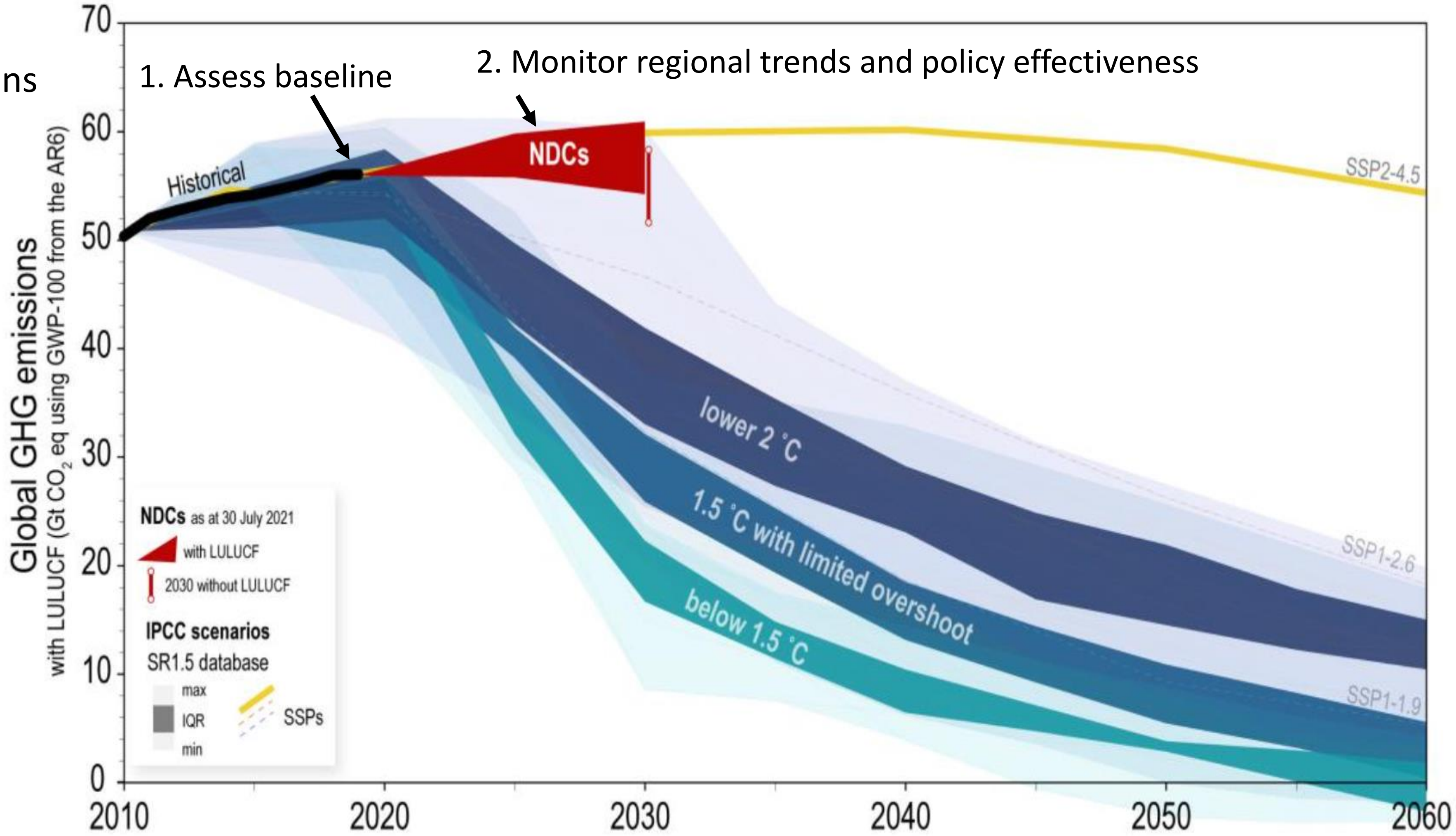
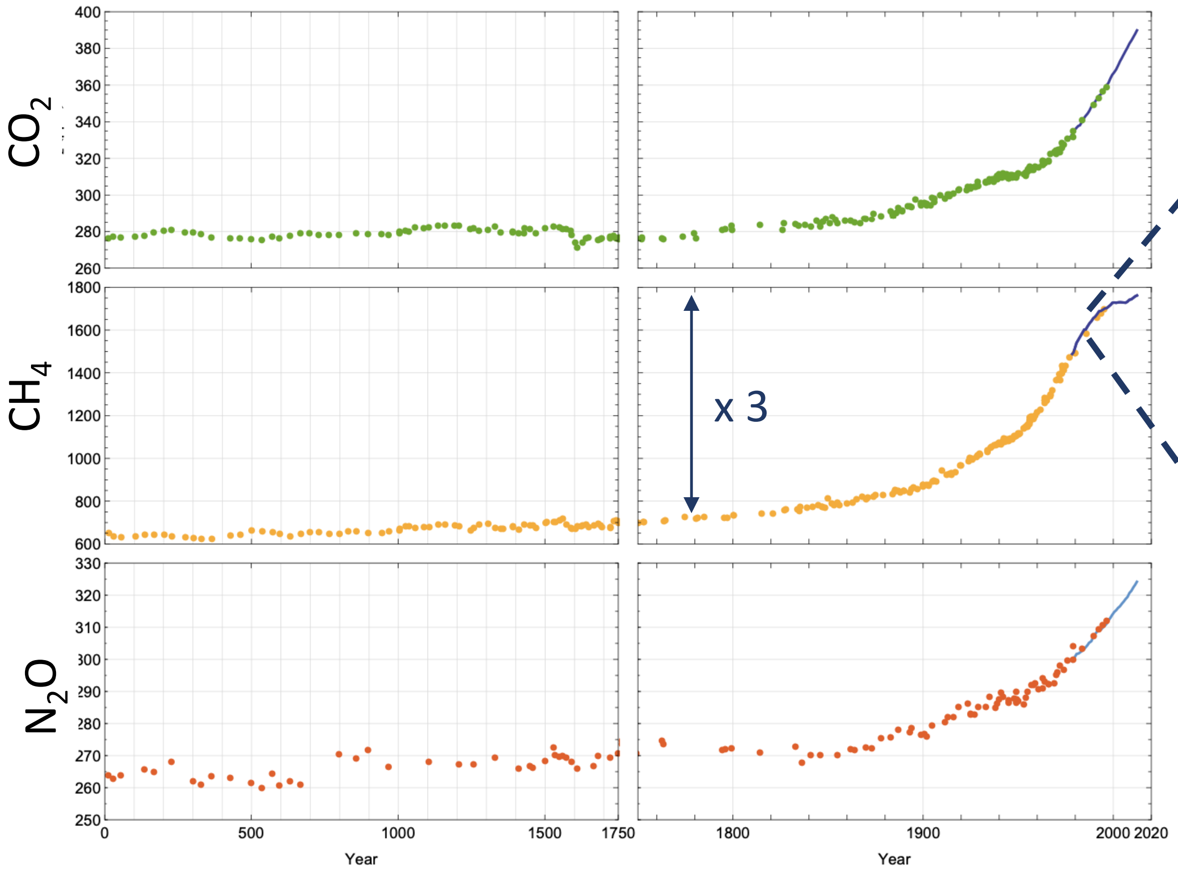
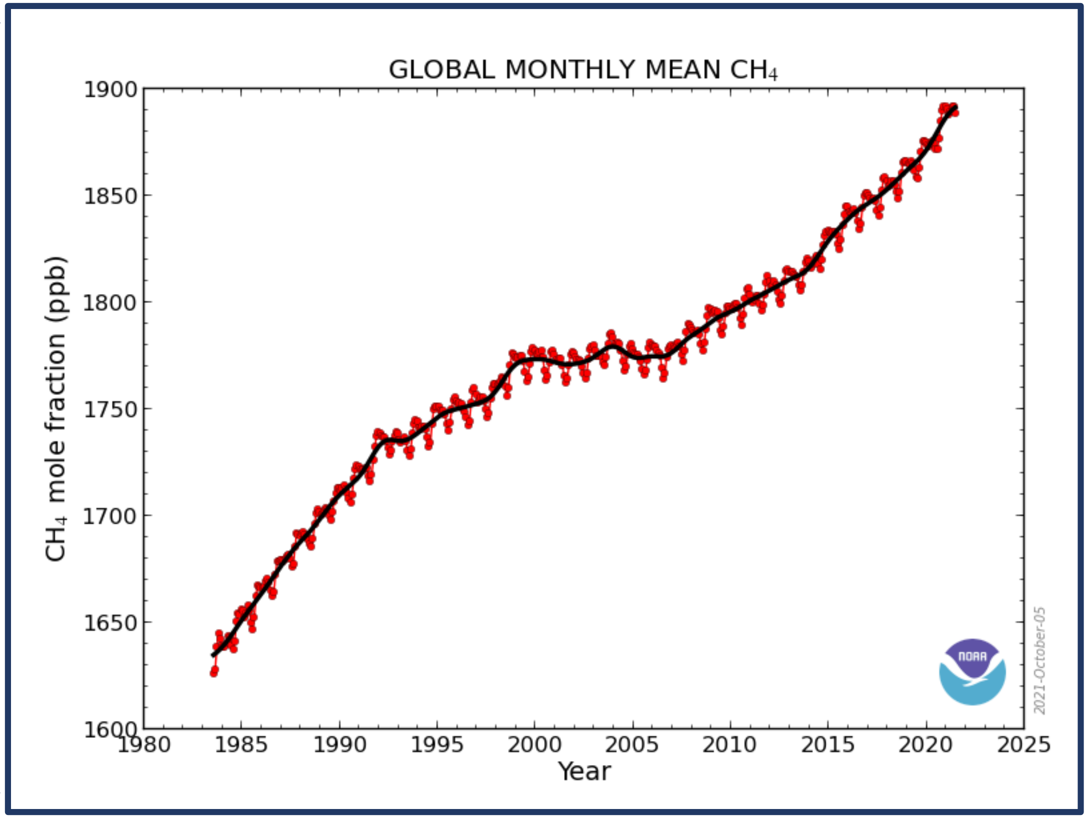
# Emission pathways in the Paris agreement

Improved information about emissions needed to :



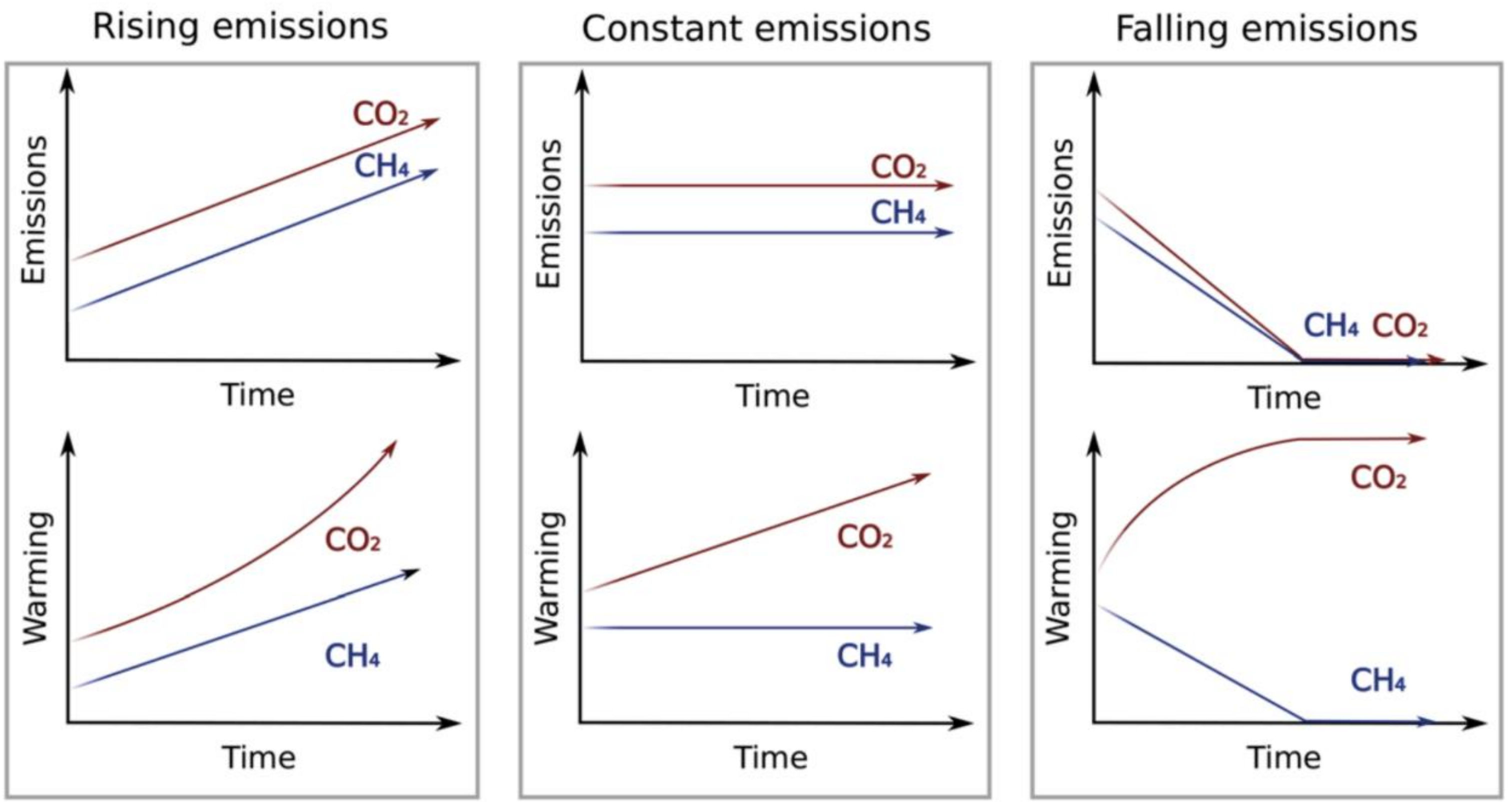
# Methane is the second most important greenhouse gas causing climate change



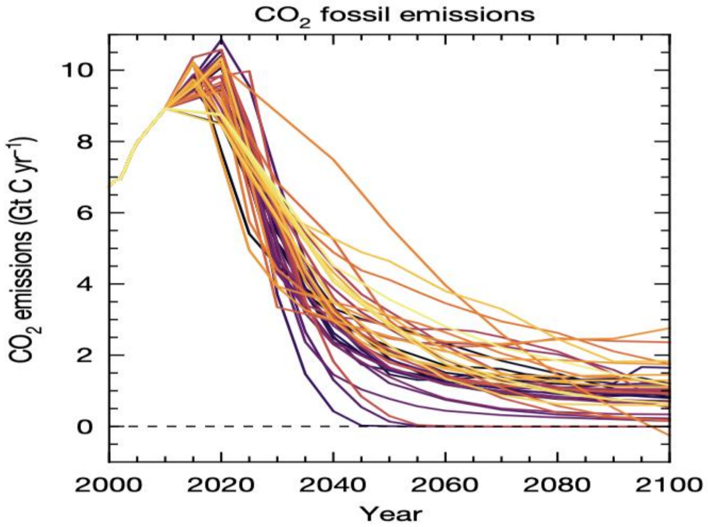



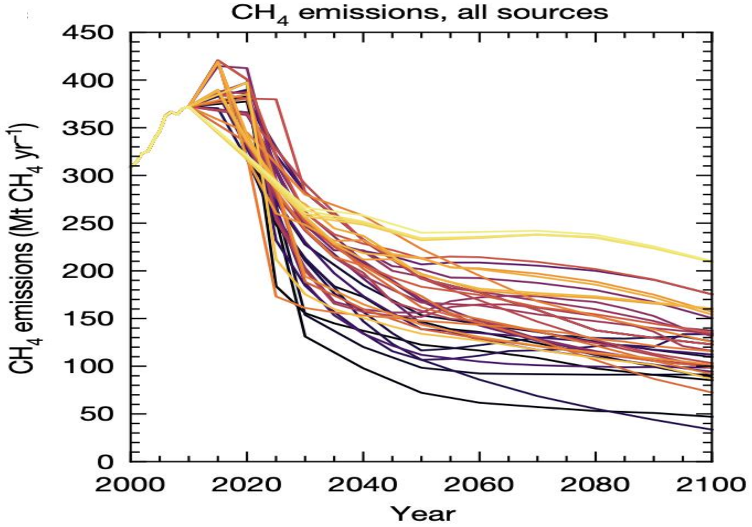

After a short plateau in the 2000s, methane is increasing at a faster rate in the recent years

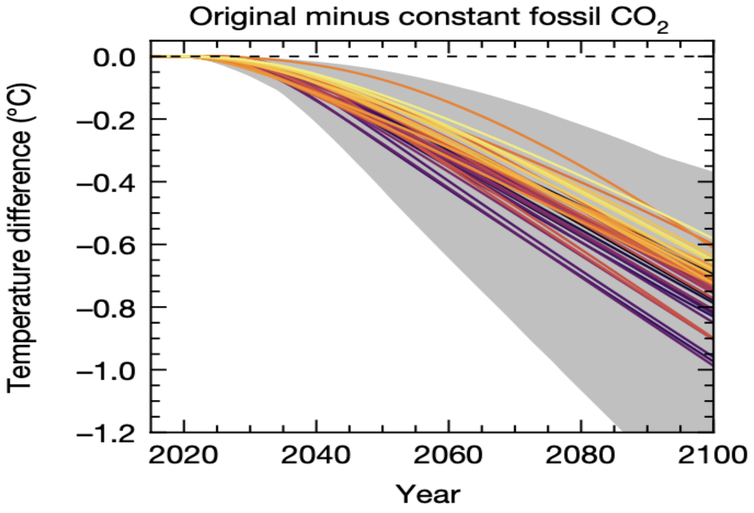
# Climate benefits of $CH_4$ emissions reductions

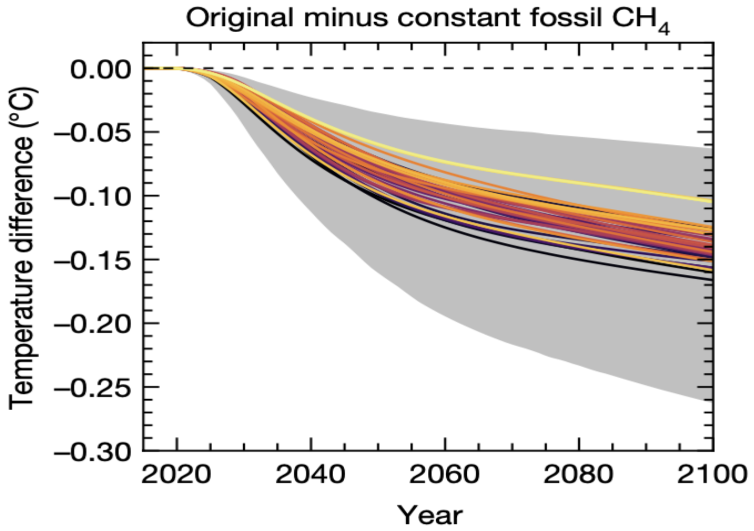


# Importance of $CH_4$ vs $CO_2$ emissions reductions for low warming scenarios



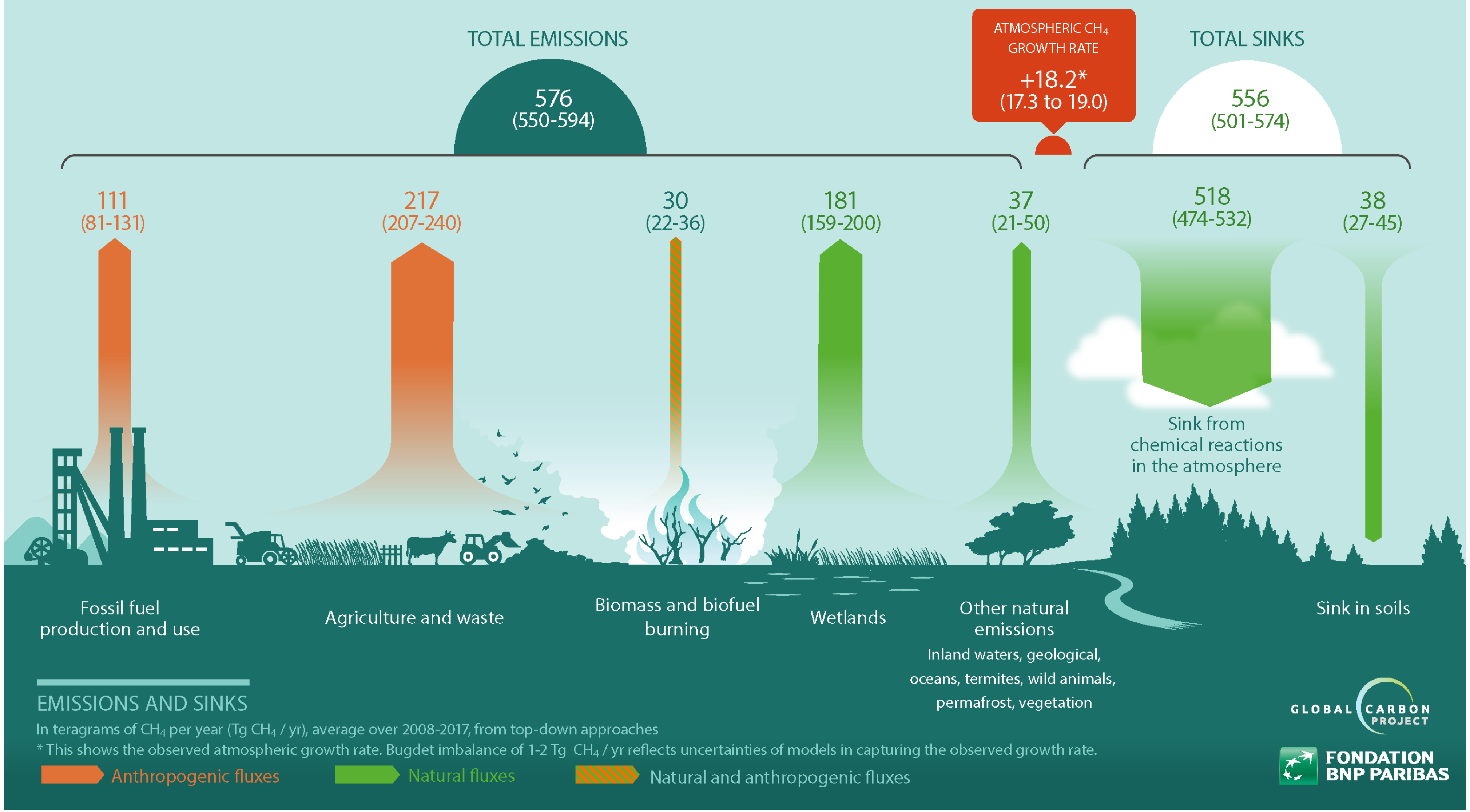



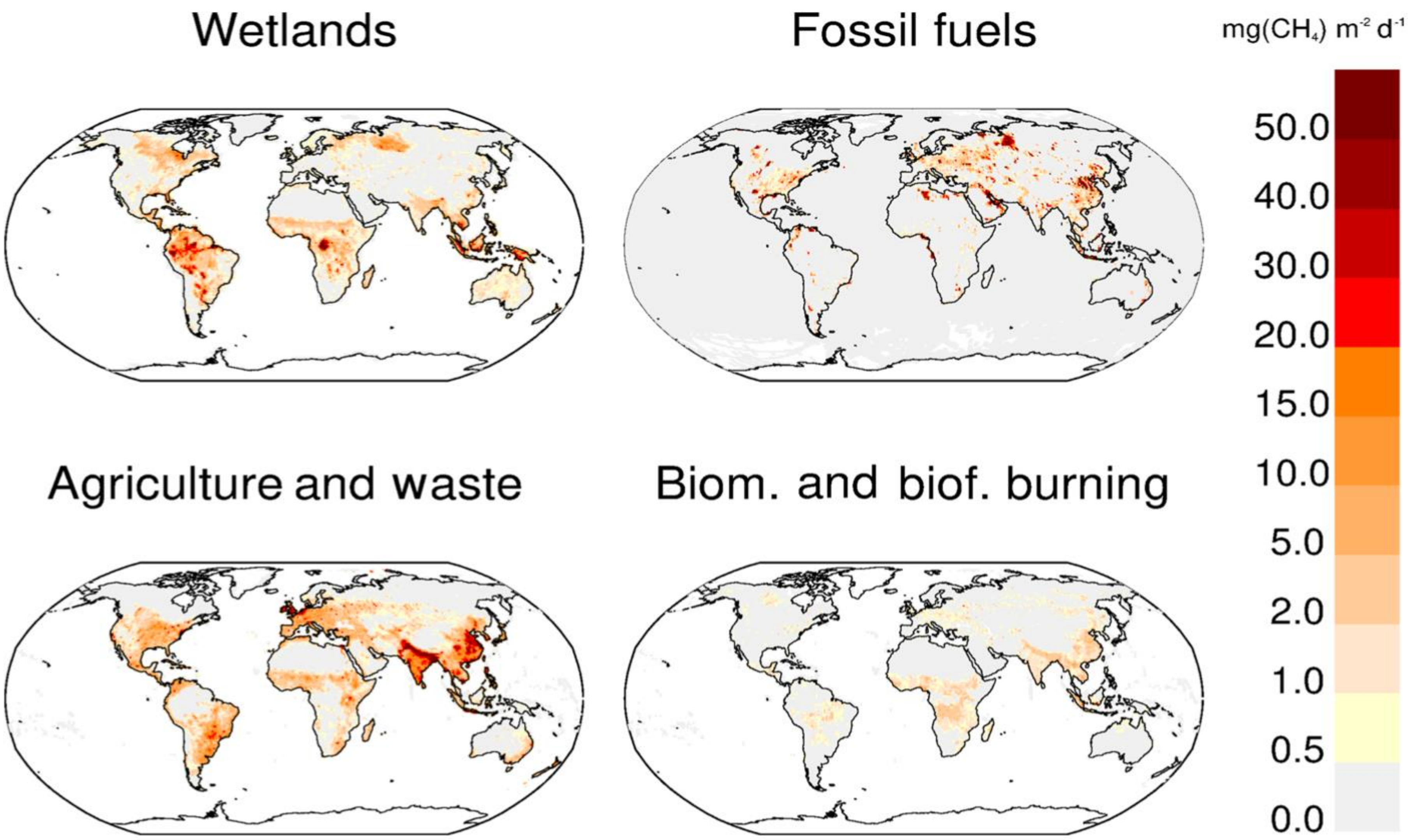




*Shindell et al. Nature 2019*

# The methane growth rate results from the imbalance between various sources and atmospheric destruction



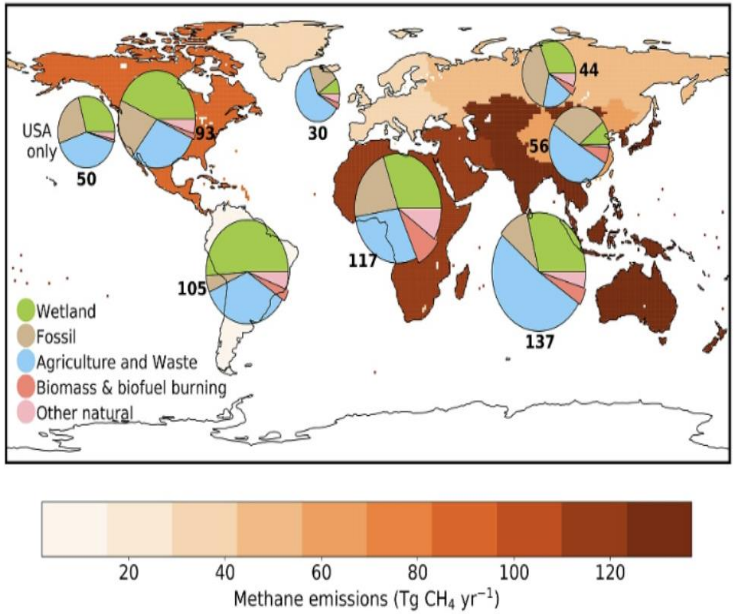
# Global (main) sources of $CH_4$ to the atmosphere



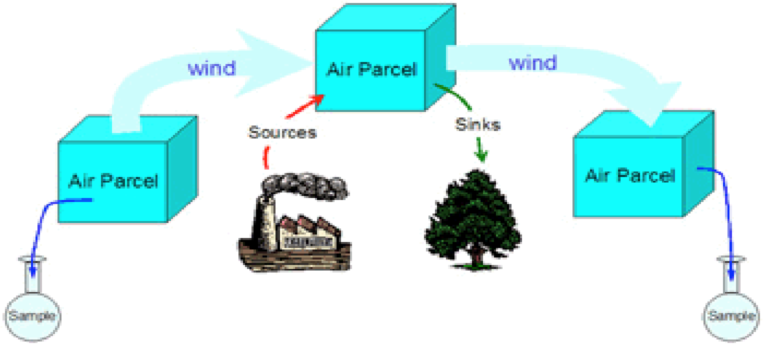
# What do atmospheric measurements tell us about global and national $CH_4$ emissions ?

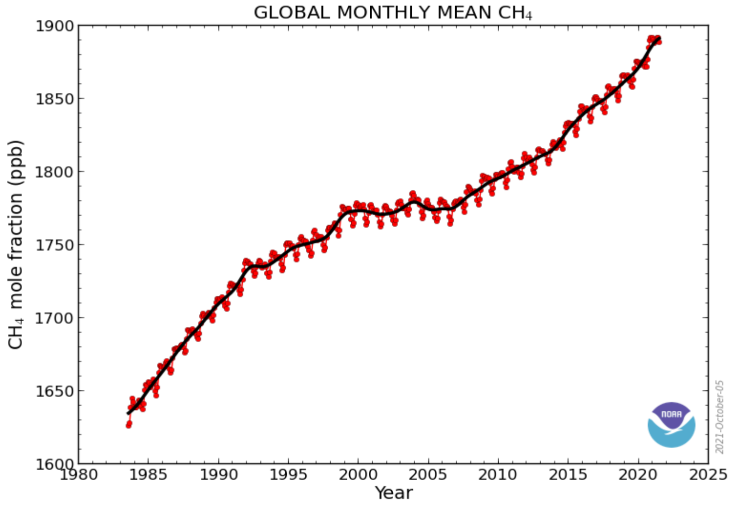
*Bottom-up and top-down*

CH4 emissions
by bottom-up inventories : energy use data, agricultural statistics, emission factors

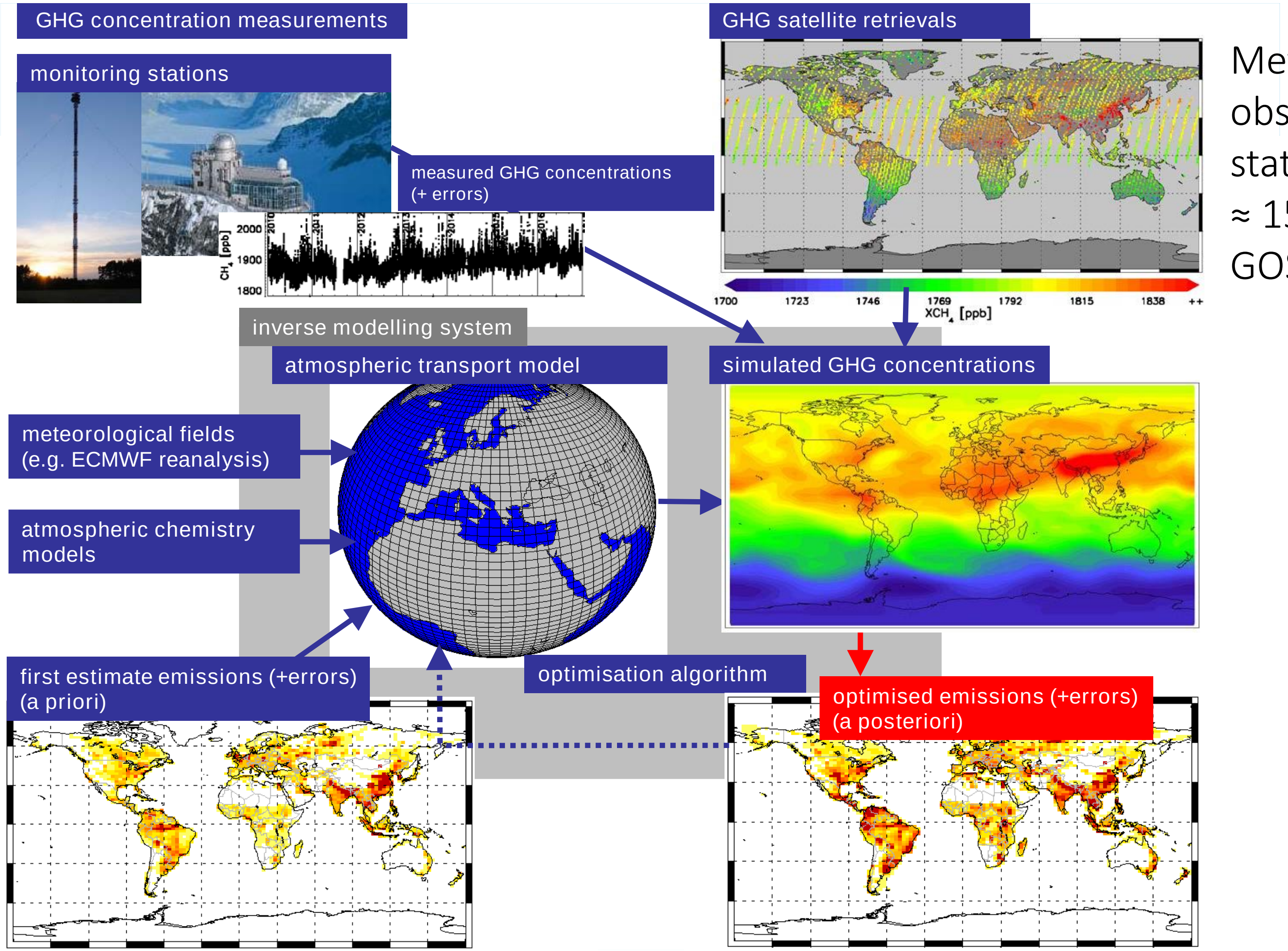



CH4 emissions by inverse modelling : prior emissions, concentration measurements and transport models



# What do atmospheric measurements tell us about global and national $CH_4$ emissions ?




Methane concentrations are observed at ground based stations since the late 1980s with ≈ 150 sites currently and with the GOSAT satellite since 2009

# How to measure GHG concentration from space?

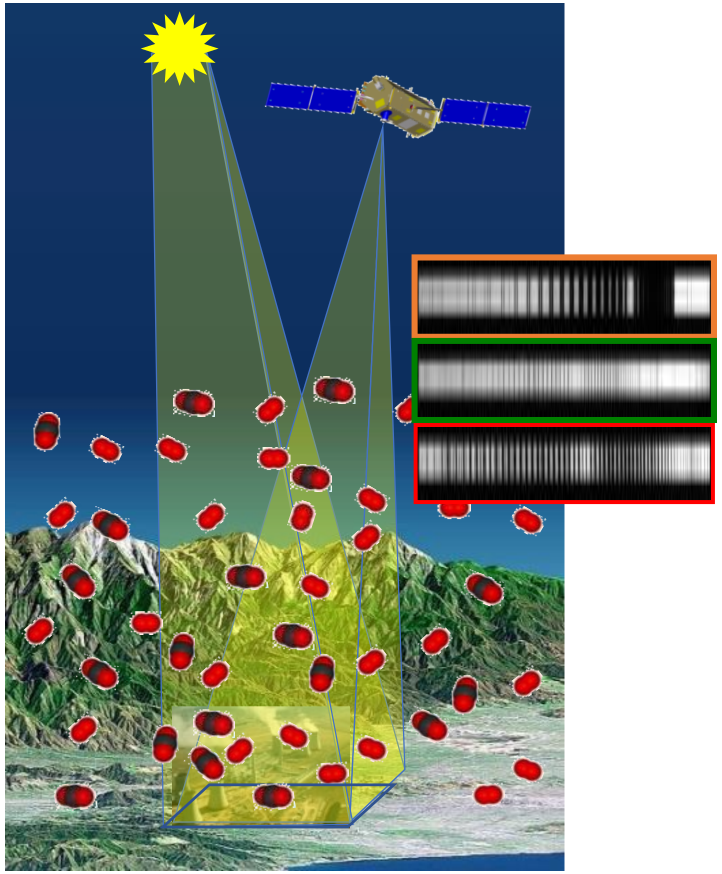
column concentration is called $XCO_2$

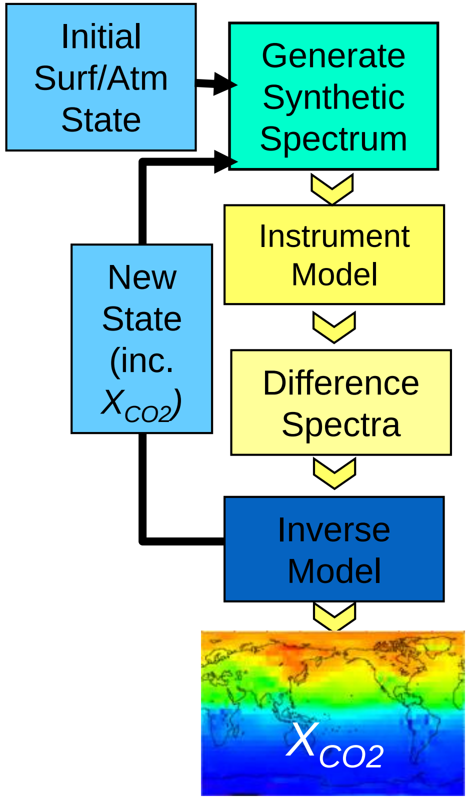
First – retrieve concentrations from absorption spectra

Record spectra of $CO_2$ and $O_2$ absorption in reflected sunlight

**Retrieve variations in the *column averaged $CO_2$ dry air mole fraction, $X_{CO2}$* over the sunlit hemisphere**

Validate measurements to ensure $X_{CO2}$ accuracy of 1 ppm (0.25%)

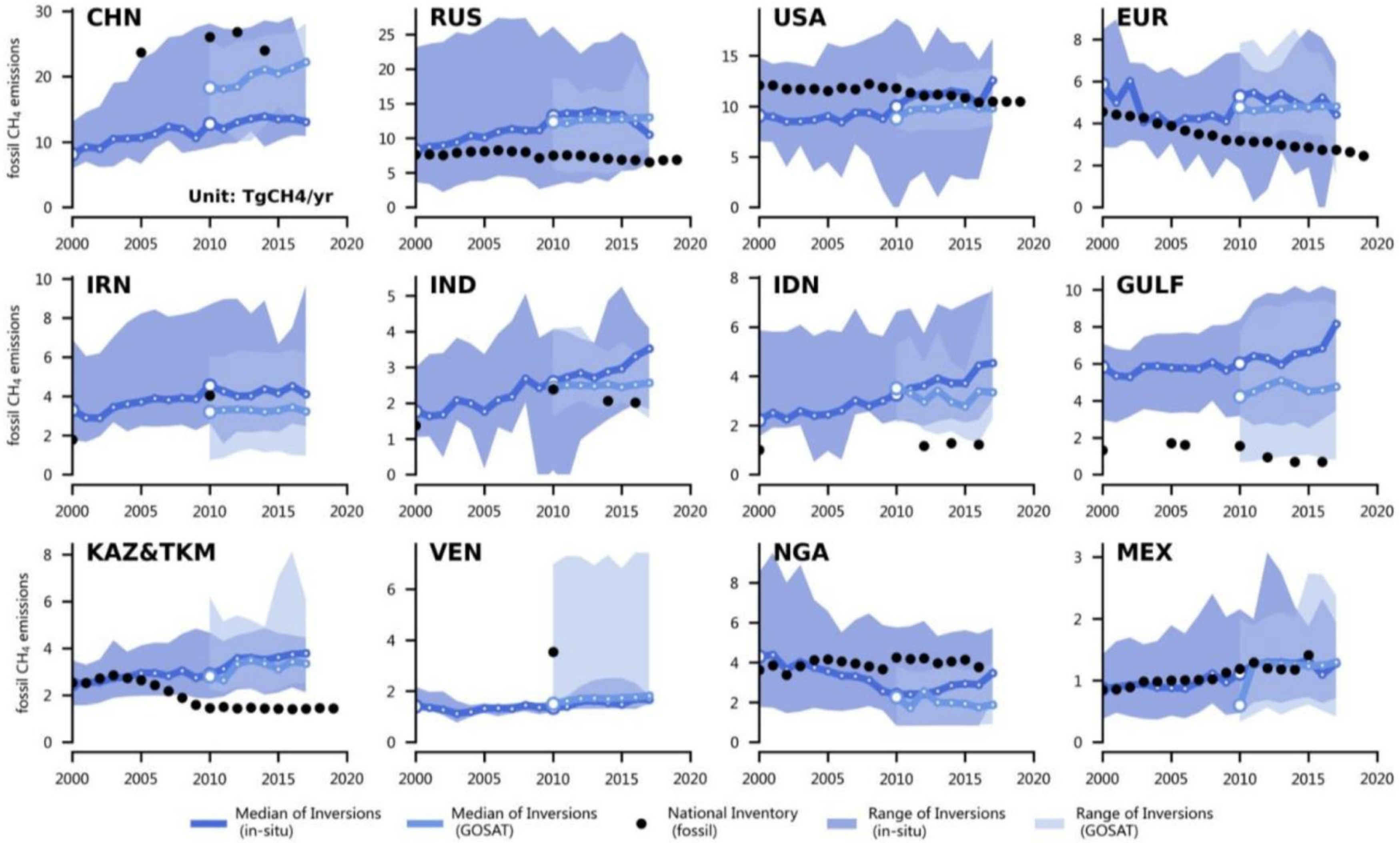




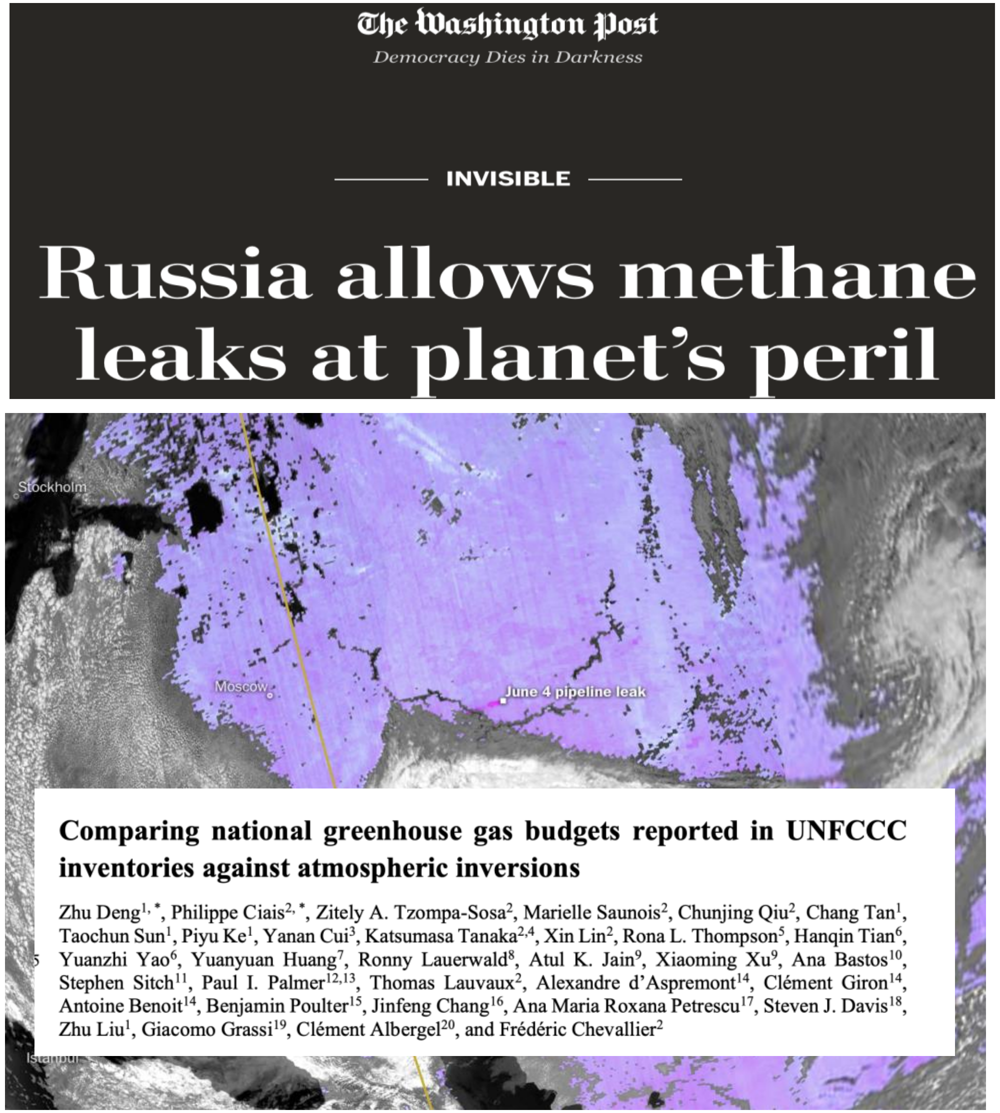


Main challenge is to separate the CO2 signal from diffusers (aerosols, thin clouds) and surface reflectance

# Comparing inventories with inversions for fossil $CH_4$ emissions : oil, gas, coal extraction & gas distribution



# Large differences between successive inventories of $CH_4$ emissions by Russia, reported to UNFCCC


The Washington Post
*Democracy Dies in Darkness*

INVISIBLE

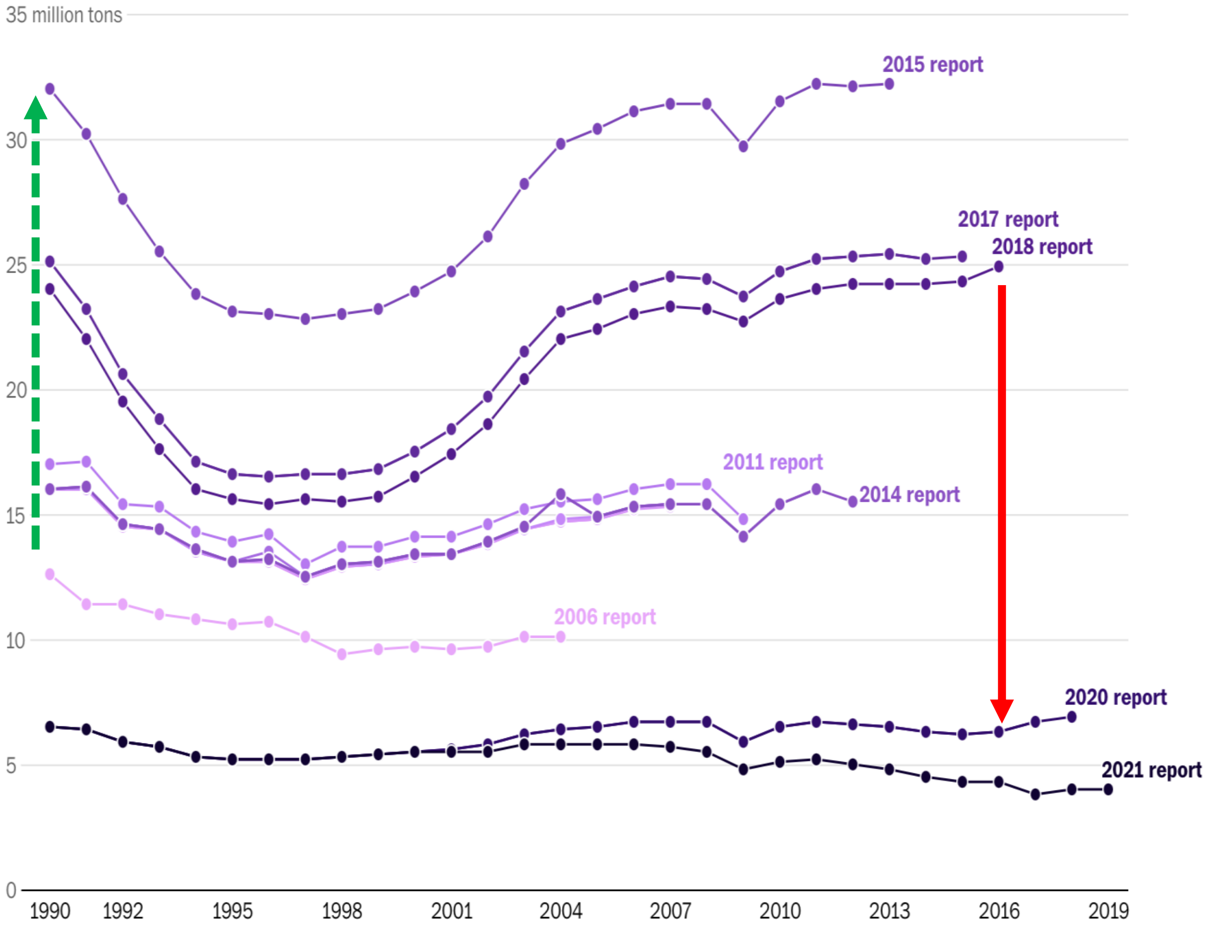
# Russia allows methane leaks at planet's peril

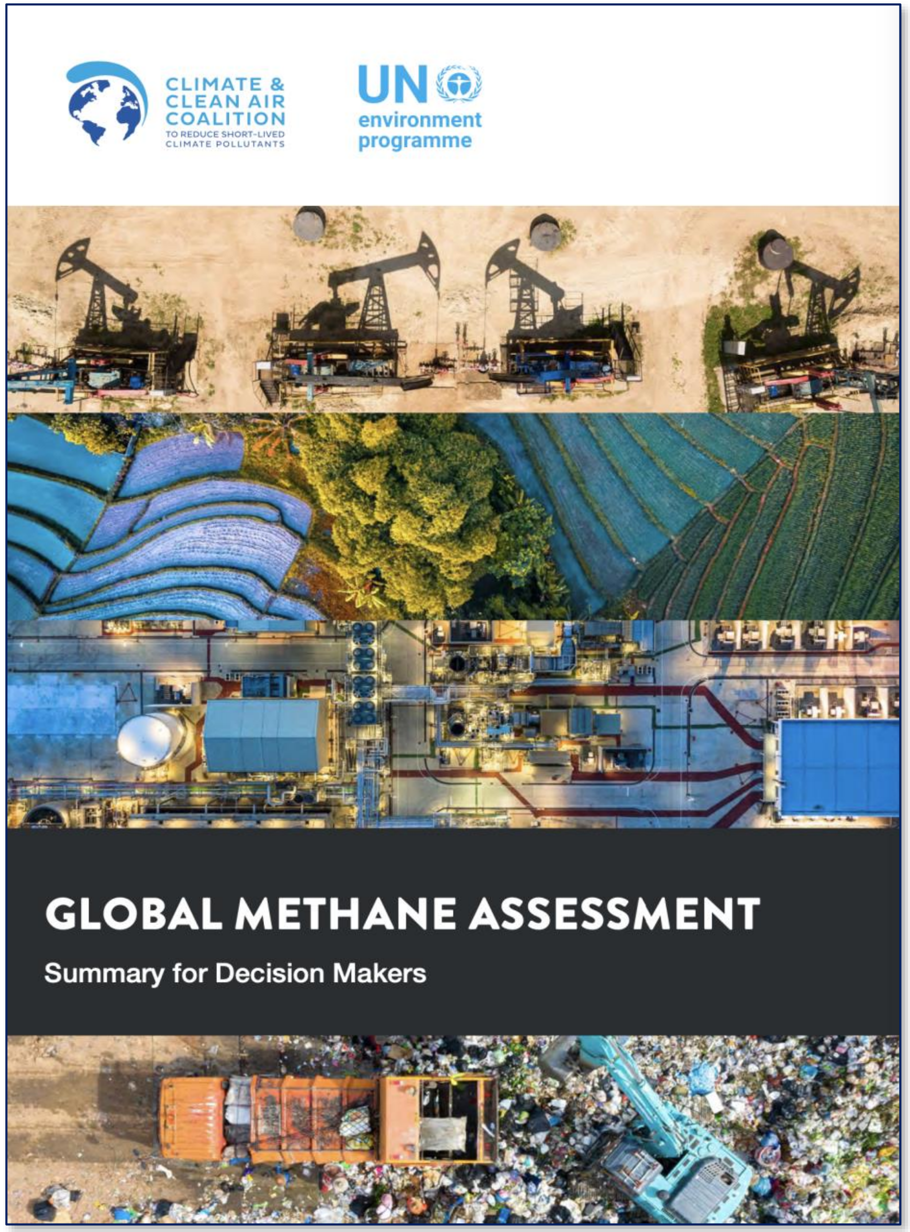


**Comparing national greenhouse gas budgets reported in UNFCCC inventories against atmospheric inversions**

Zhu Deng[1,*], Philippe Ciais[2,*], Zitely A. Tzompa-Sosa[2], Marielle Saunois[2], Chunjing Qiu[2], Chang Tan[1], Taochun Sun[1], Piyu Ke[1], Yanan Cui[3], Katsumasa Tanaka[2,4], Xin Lin[2], Rona L. Thompson[5], Hanqin Tian[6], Yuanzhi Yao[6], Yuanyuan Huang[7], Ronny Lauerwald[8], Atul K. Jain[9], Xiaoming Xu[9], Ana Bastos[10], Stephen Sitch[11], Paul I. Palmer[12,13], Thomas Lauvaux[2], Alexandre d'Aspremont[14], Clément Giron[14], Antoine Benoit[14], Benjamin Poulter[15], Jinfeng Chang[16], Ana Maria Roxana Petrescu[17], Steven J. Davis[18], Zhu Liu[1], Giacomo Grassi[19], Clément Albergel[20], and Frédéric Chevallier[2]

Oct. 19, 2021





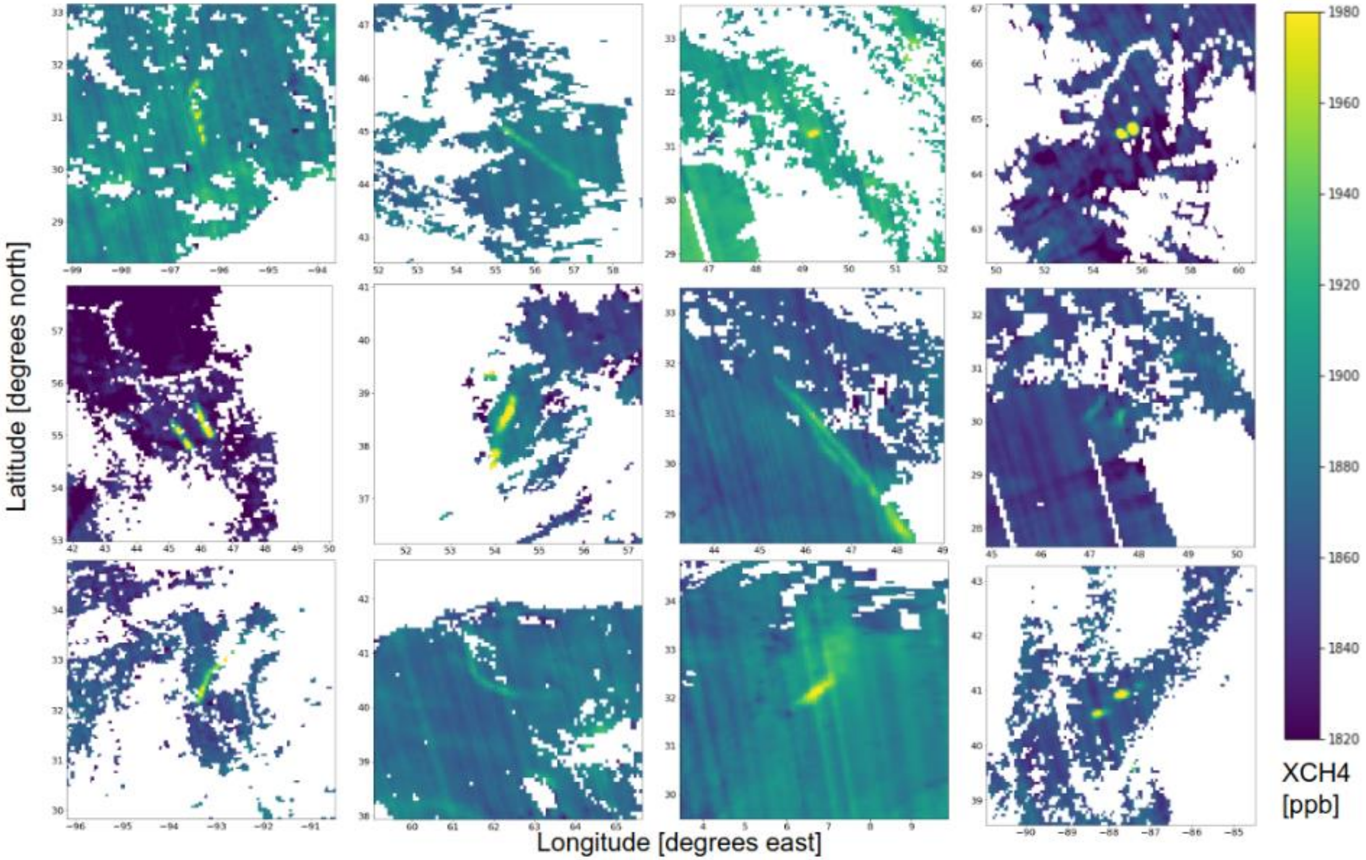

Currently available measures could reduce emissions from major sectors by approximately 180 Mt/yr, or as much as 45 per cent, by 2030. This is a cost-effective step required to achieve the United Nations Framework Convention on Climate Change (UNFCCC) 1.5° C target

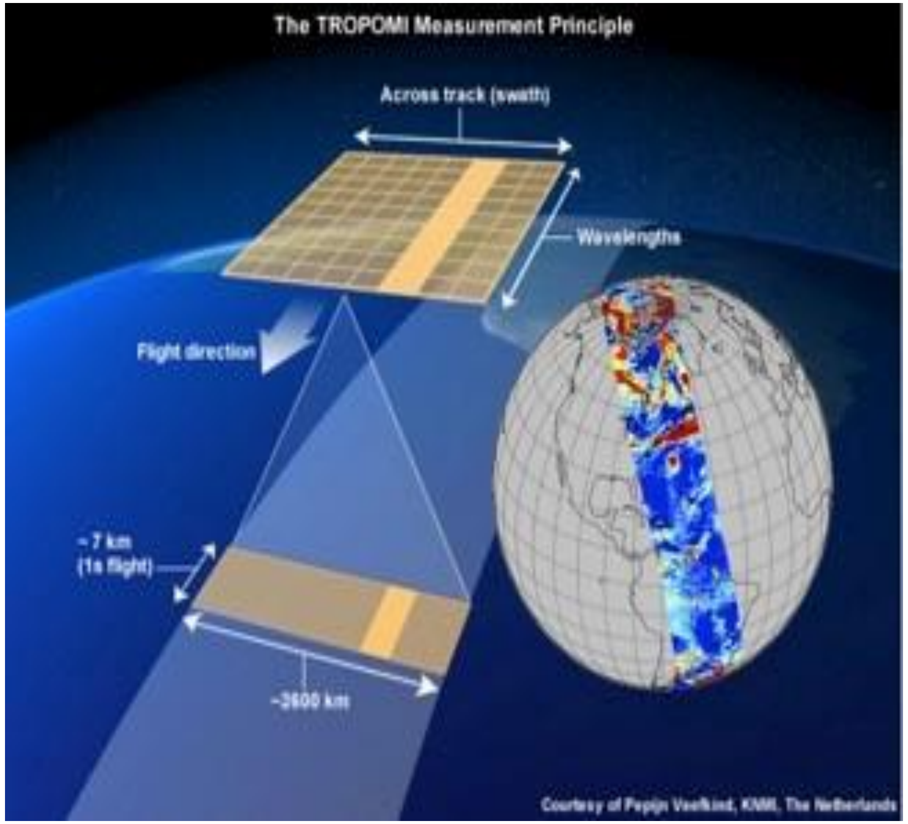
There are readily available targeted measures that can reduce 2030 methane emissions by 30 per cent, around 120 Mt/yr. **Nearly half of these technologies are available to the fossil fuel sector** in which it is relatively easy to reduce

This assessment led to the **Glasgow methane pledge** in which 103 countries engaged to cut emissions by 30% in 2030 mainly in the fossil sector

**How can we monitor progress towards this commitment ?**

# Satellite detection of methane plumes over fossil fuel production sites and basins




Data : Kayrros Global Methane Watch
Lauvaux et al. Science 2022

KAYRROS

# Satellite detection of methane plumes over fossil fuel production sites and basins

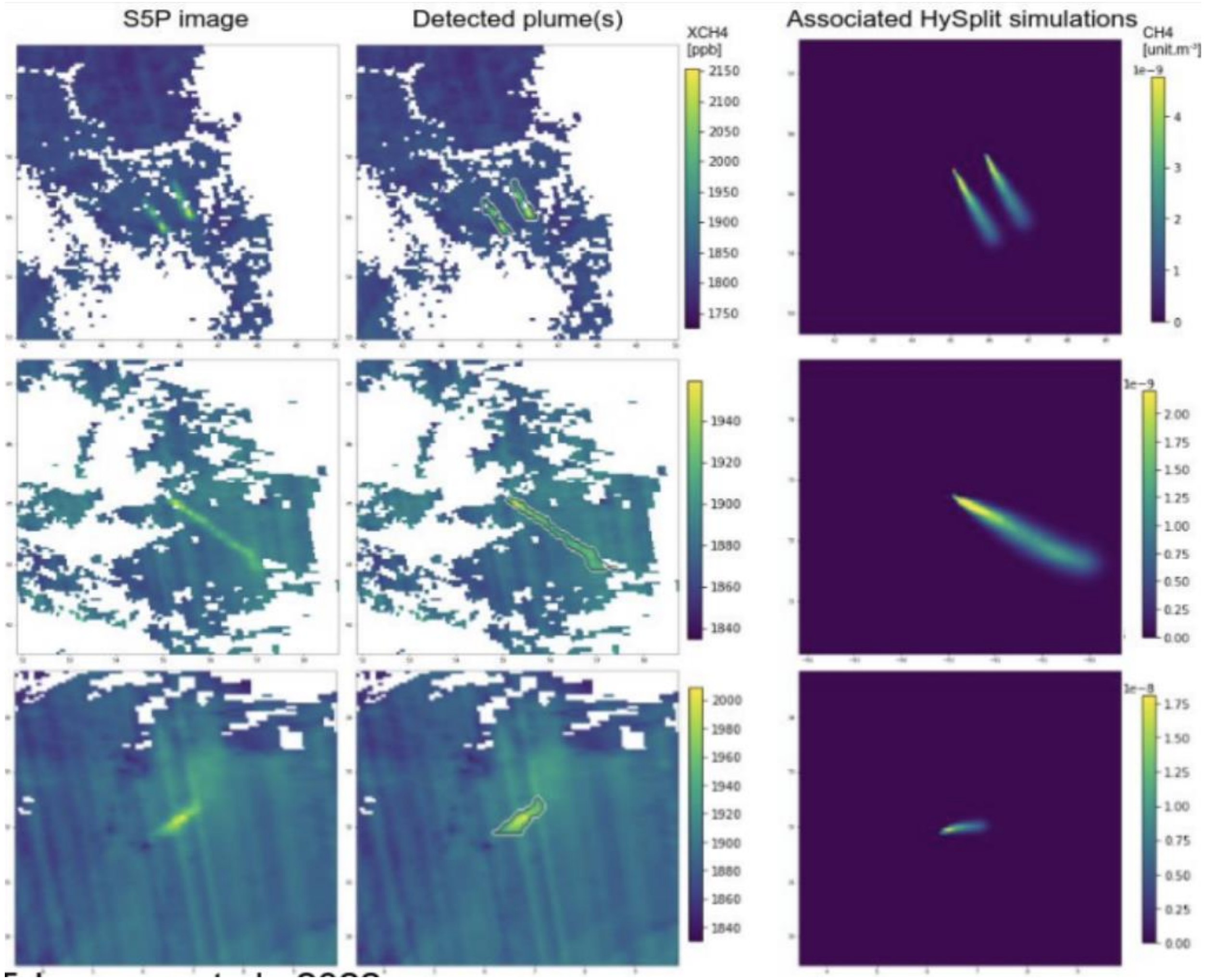
## Processing pipeline

1. Detect anomalous methane concentrations automatically: gaussian denoising, local background estimation, segment and deblend plumes, estimate source location

2. Human labelling/checking, false positives removal

3. Quantify flow rates using HYSPLIT: simulate methane plumes and find the best fit between simulation and observation

4. Human check, spurious quantifications removed




Data : Kayrros Global Methane Watch
Lauvaux et al. Science 2022

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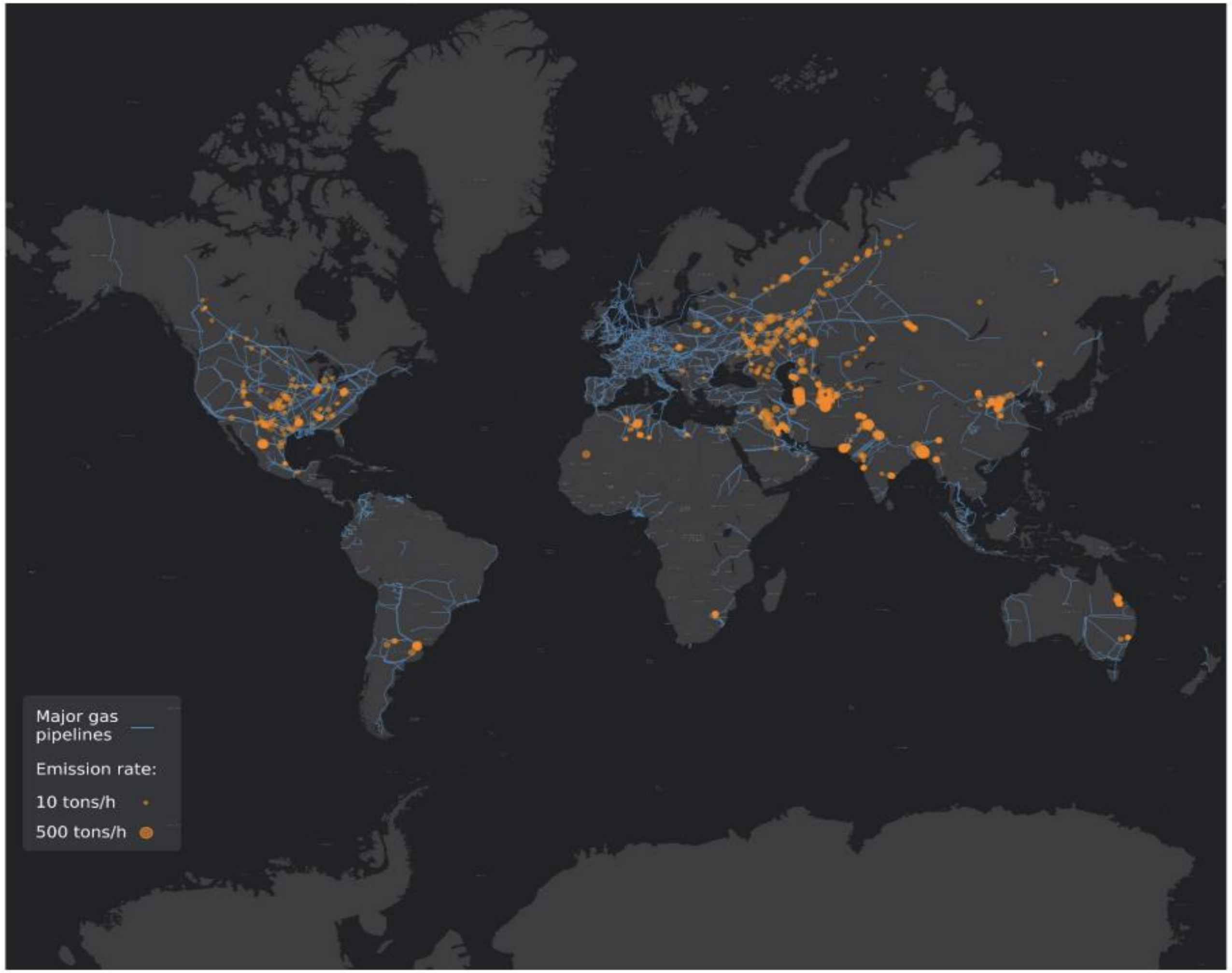
# Sentinel-5P near-real time monitoring




RESEARCH

GREENHOUSE GASES

## Global assessment of oil and gas methane ultra-emitters

T. Lauvaux[1]*, C. Giron[2], M. Mazzolini[2], A. d'Aspremont[2,3], R. Duren[4,5], D. Cusworth[6], D. Shindell[7,8,9], P. Ciais[1,10]

Methane emissions from oil and gas (O&G) production and transmission represent a considerable contribution to climate change. These emissions comprise sporadic releases of large amounts of methane during maintenance operations or equipment failures not accounted for in current inventory estimates. We collected and analyzed hundreds of very large releases from atmospheric methane images sampled by the TROPOspheric Monitoring Instrument (TROPOMI) between 2019 and 2020. Ultra-emitters are primarily detected over the largest O&G basins throughout the world. With a total contribution equivalent to 8 to 12% (~8 million metric tons of methane per year) of the global O&G production methane emissions, mitigation of ultra-emitters is largely achievable at low costs and would lead to robust net benefits in billions of US dollars for the six major O&G-producing countries when considering societal costs of methane.

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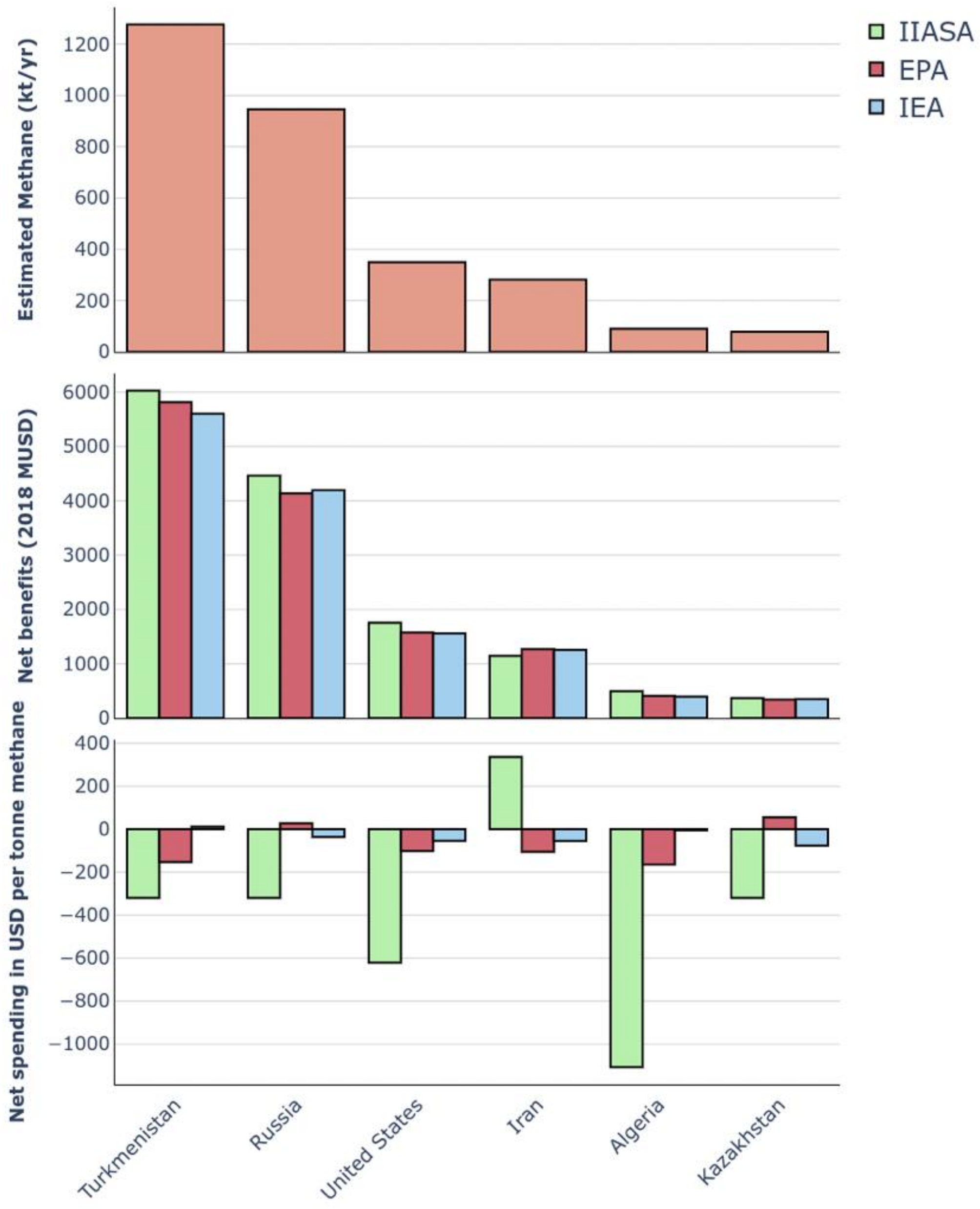
# Fixing large $CH_4$ leaks




*Data : Lauvaux et al. and Kayrros Global Methane watch*

## Will deliver immediate and important financial and societal benefits

11-13 billion US$ benefits for the six countries considered according to three different technological assessments

Benefits include gas savings, avoided warming and positive human health outcomes through ozone exposure

# Emissions at the scale of large basins

US Permian basin emissions variations

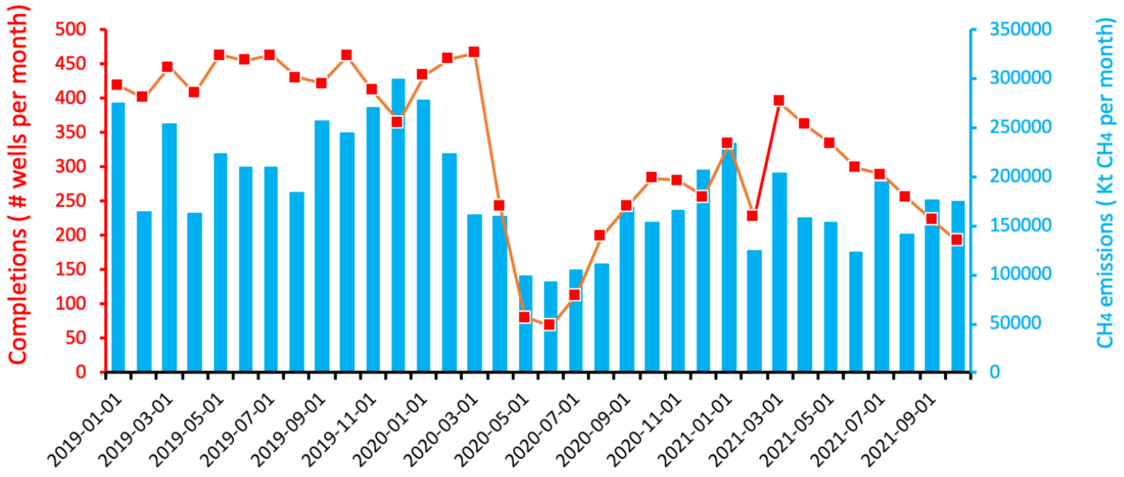
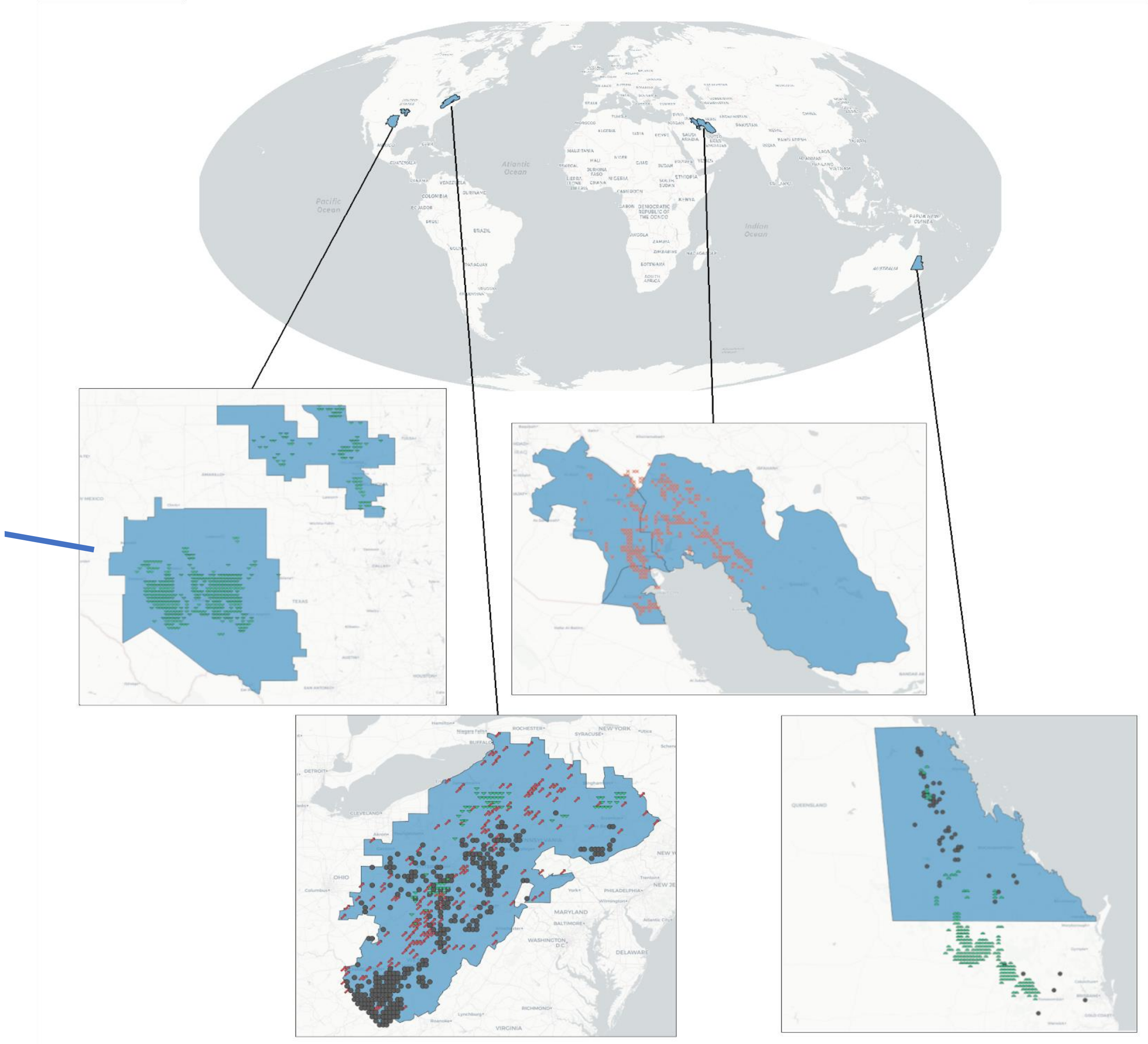



Figure 2. Emissions of $CH_4$ (blue) from the Permian shale oil and gas basin in the US and well completion rates (red).



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# Next steps : emissions at the scale of large basins

***General framework:***

**MIN** $(y - Kx)^2 + \lambda_1||x||_1 + \lambda_2||x||_2$

**SUCH THAT**

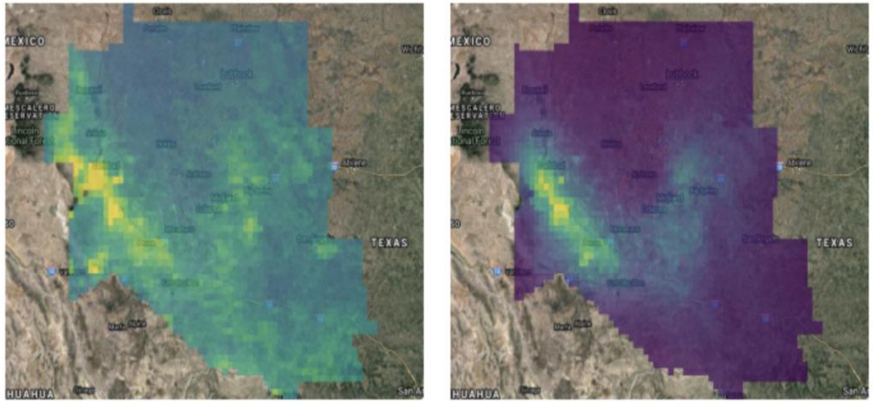
- only a subset of pixels can emit
- $x \geqslant 0$
- Basin-specific constraints

***y*** = S5P methane **enhancement**
***K*** = emissions "footprint" (**Hysplit**)
***x*** = emission rates
***Lambdas*** regularize the output (L1 penalization for OG, L2 for coal) → defined with a condition number criterion

Similar approach and results Zhang et al. (2020) [4] // Main differences:

- Rather than regularizing using a Bayesian prior, we use L1/L2 penalties
- We process single daily images rather than averaging over a period of time

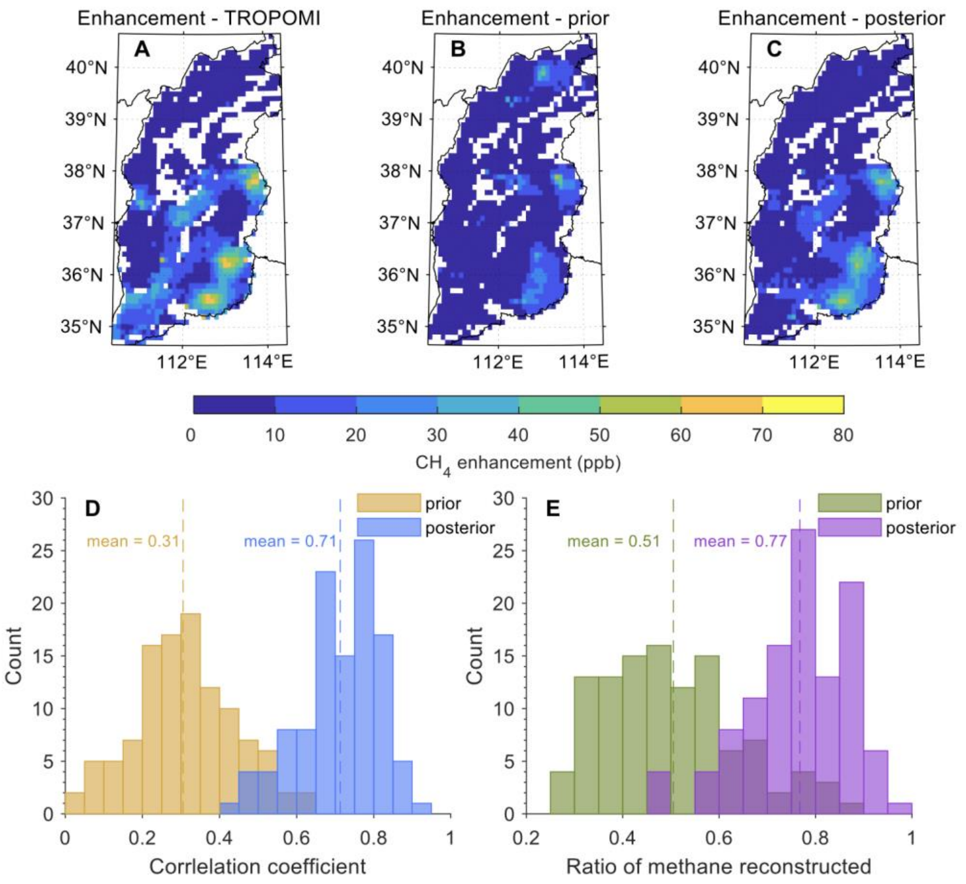
**Observed** concentrations averaged over 2020

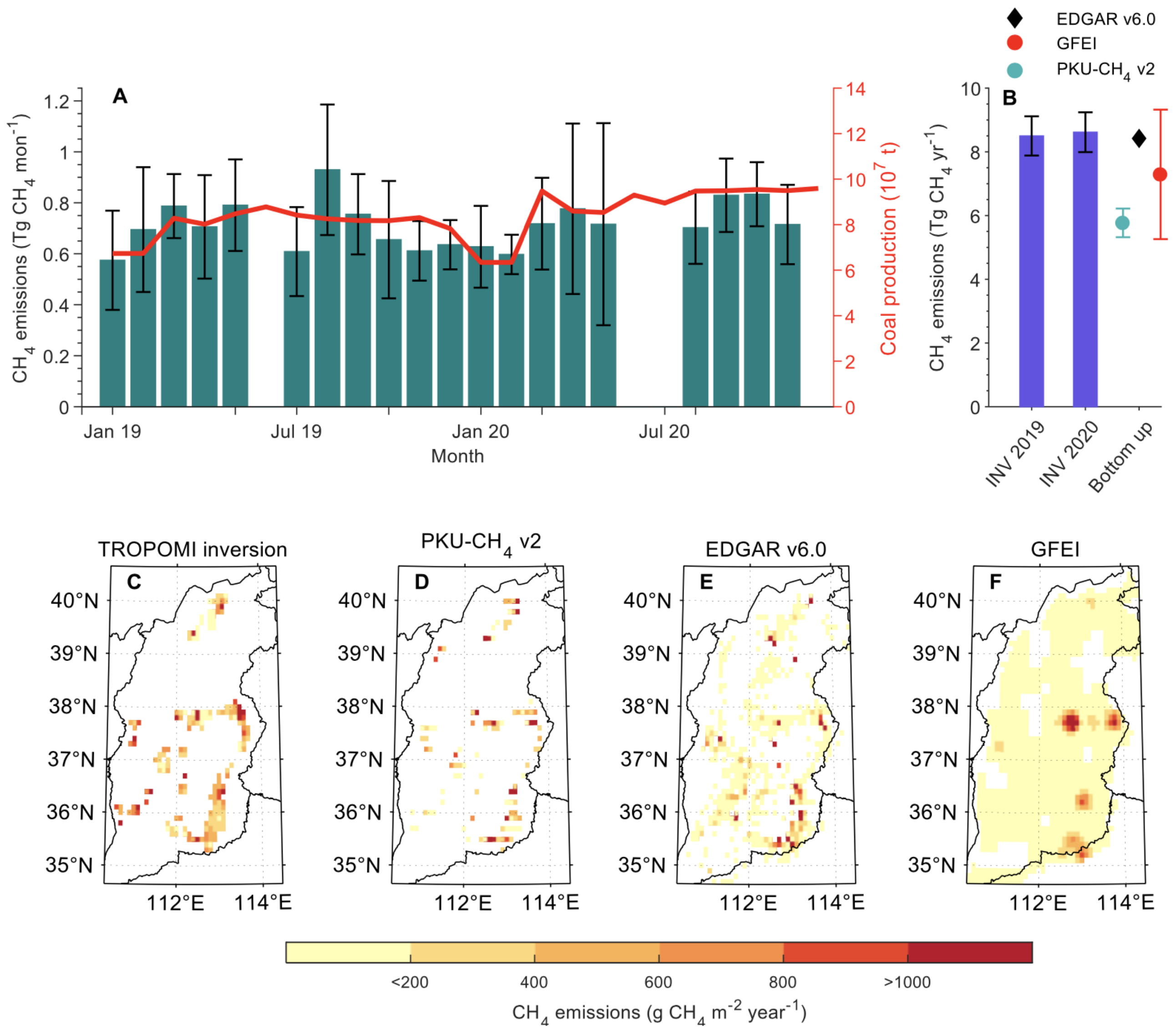



**Simulated** enhancement averaged over 2020

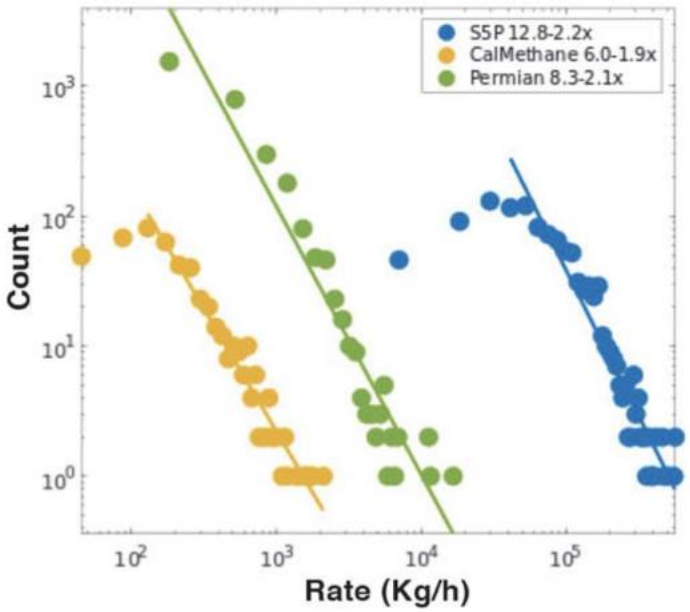
C. Giron pers. Com

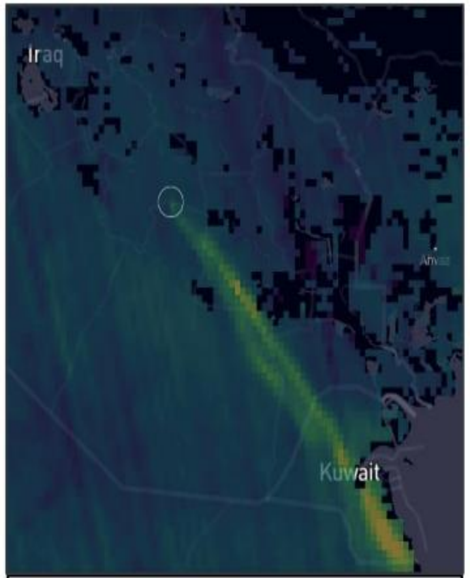
# Tropomi inversion over Shanxi



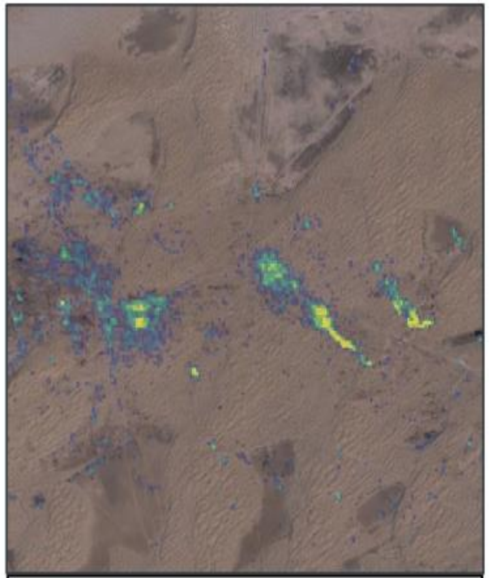
# Next steps
# Multispectral and hyperspectral images processing




**Sentinel-5P**
*5km spatial resolution*
*5-25t/h detection threshold*

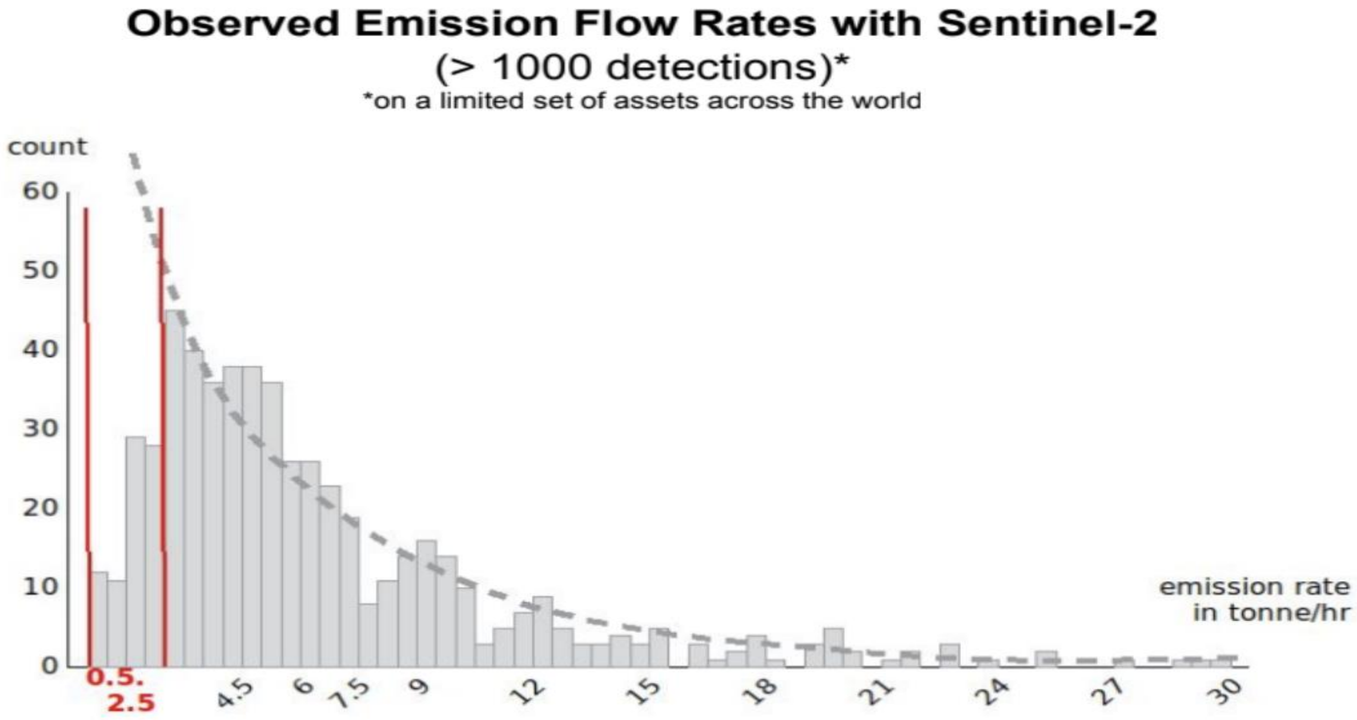
**Sentinel-2 / Landsat-8/9**
*20m spatial resolution*
*1 - 2,5 t/h detection threshold*

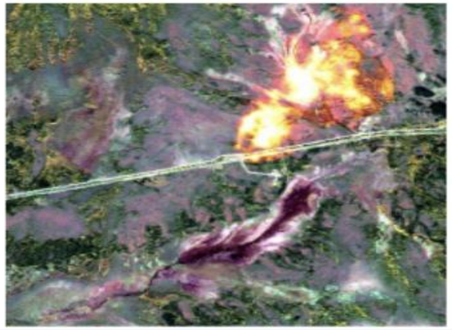


**PRISMA**
*30m spatial resolution*
*~500 kg/h detection threshold*

**Sensor-agnostic technology** to detect methane plumes from **hyperspectral/multispectral sensors**

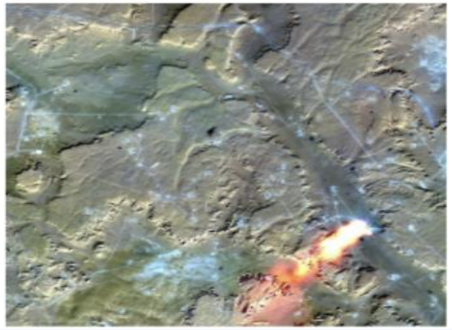
# Towards Facility-level attribution



Russia

Kazakhstan



Algeria

# What can we do ?

Technology exists for reducing leaks in the oil and gas sector

Very large differences in $CH_4$ leaks across countries

Immediate and large climate benefits

Improved regulation is needed, relying on improved emission inventories with near real time satellite monitoring

# Thank you for your attention

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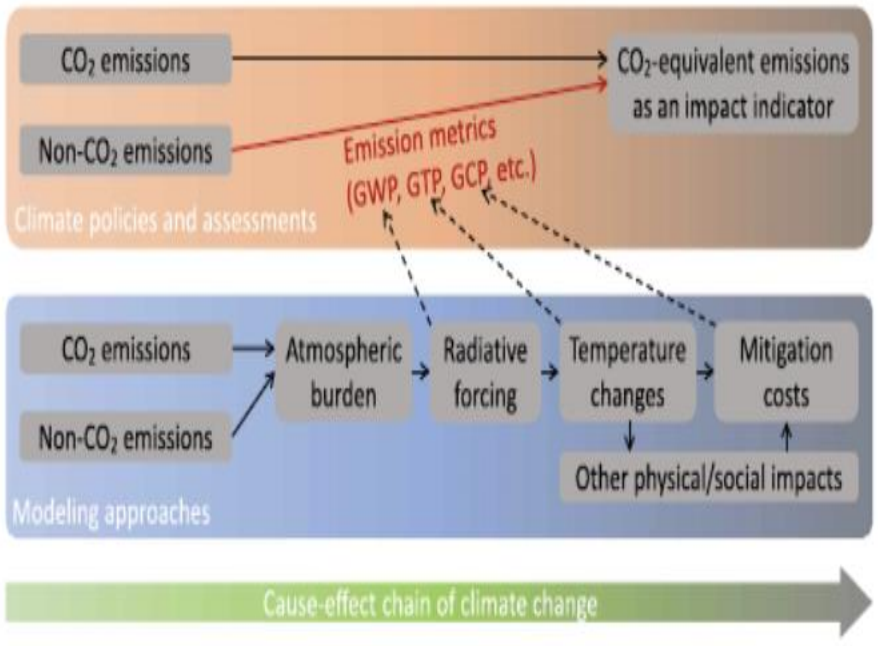
# Metrics to compare $CH_4$ with $CO_2$

SCIENCE ADVANCES | RESEARCH ARTICLE

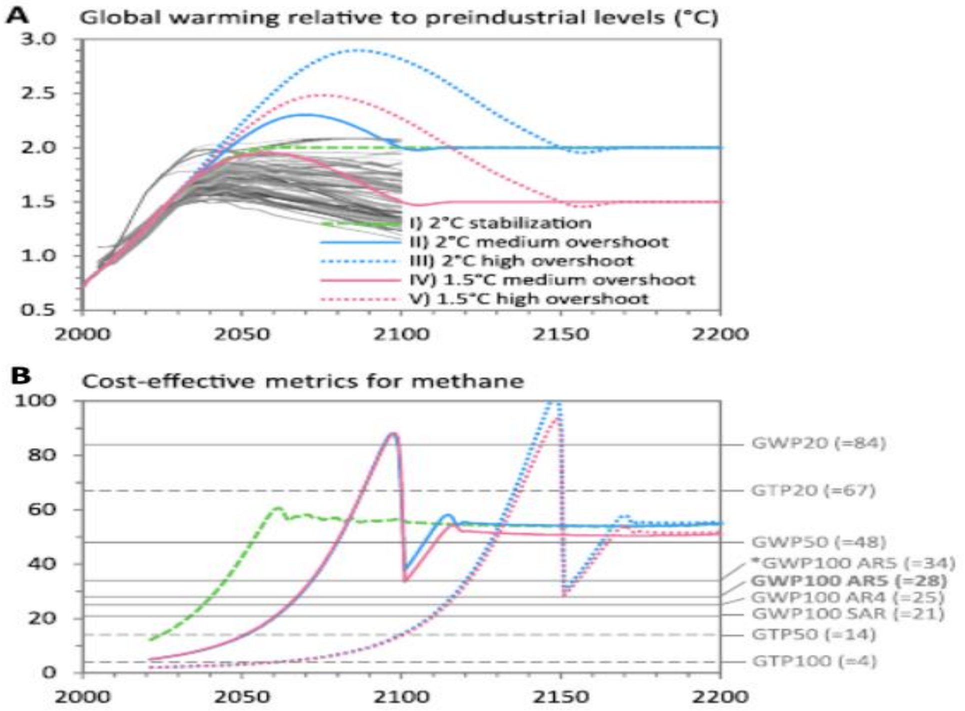
CLIMATOLOGY

## Cost-effective implementation of the Paris Agreement using flexible greenhouse gas metrics

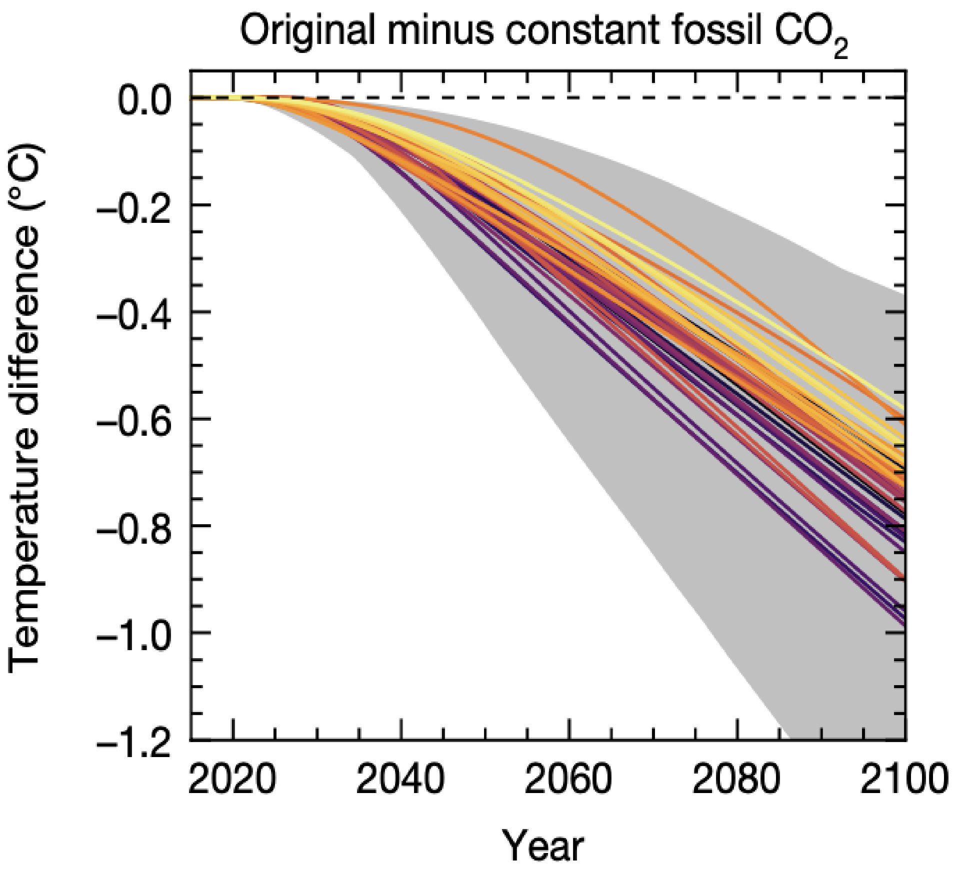
Katsumasa Tanaka[1,2,3]*, Olivier Boucher[2], Philippe Ciais[1], Daniel J. A. Johansson[4], Johannes Morfeldt[4]

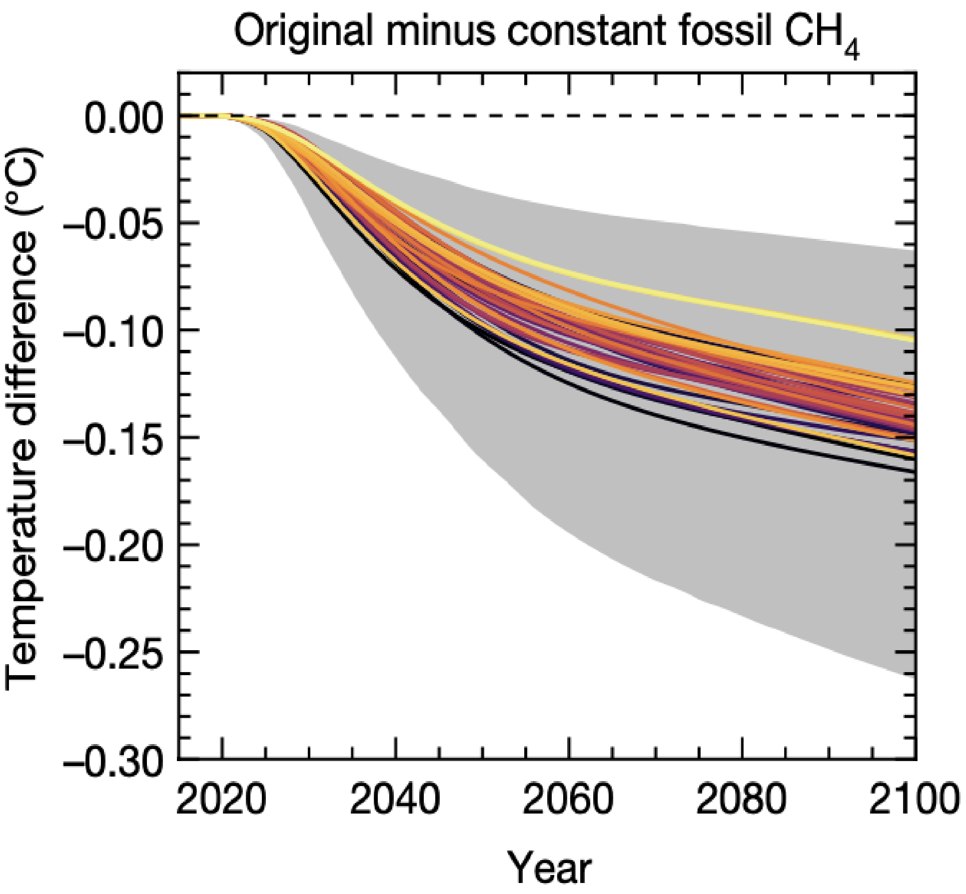



Cost-effective metrics for methane that minimize the overall mitigation costs are time-dependent, primarily determined by the pathway, and strongly influenced by temperature overshoot



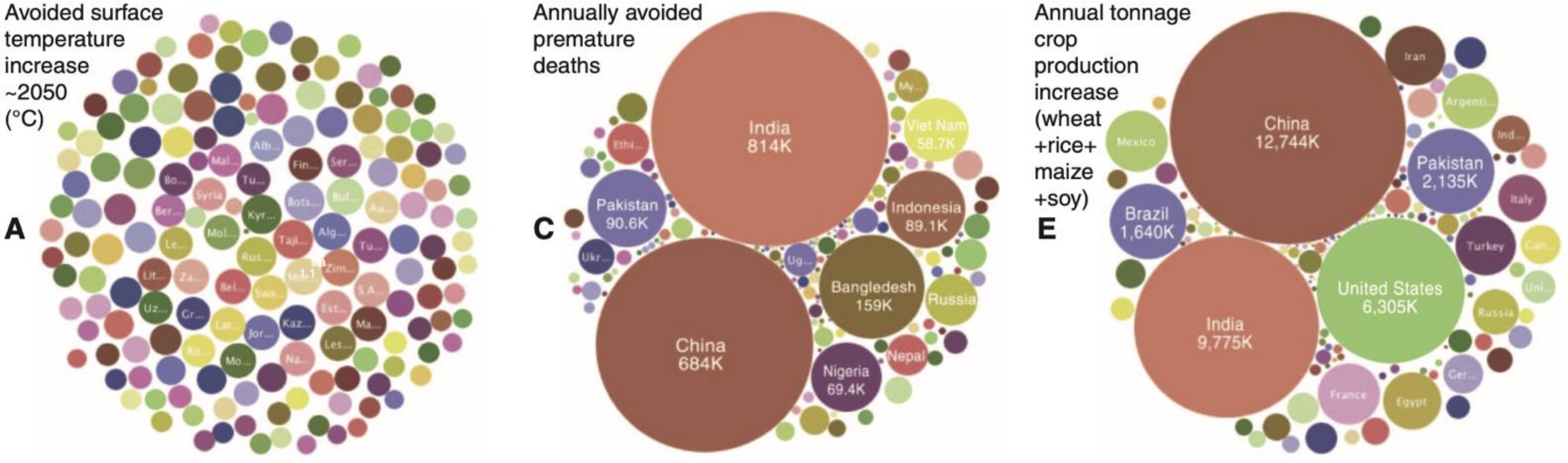
# Importance of $CH_4$ emissions reductions to reach climate stabilization in low warming scenarios



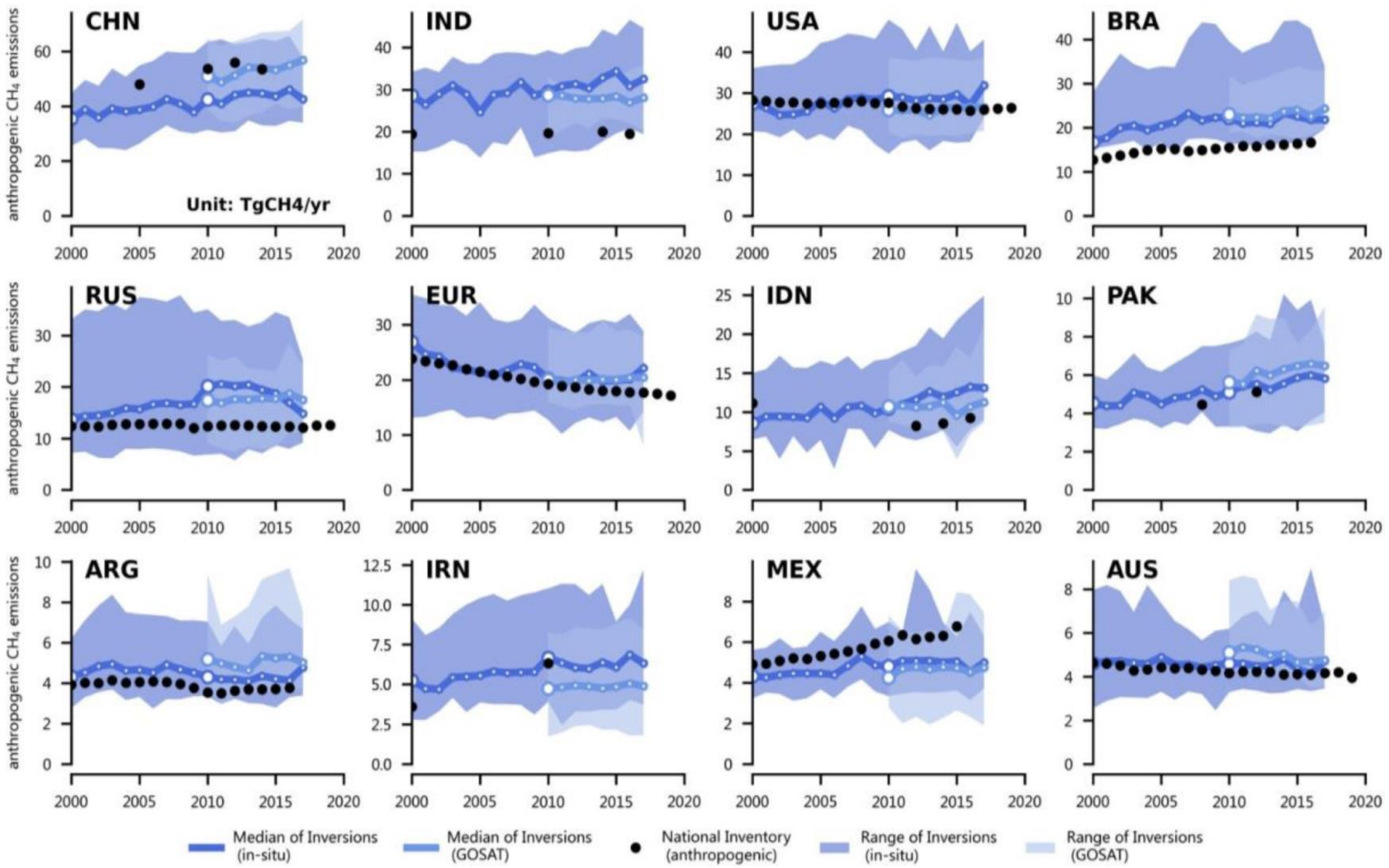

*Shindell et al. Nature 2019*

# Co-benefits of $CH_4$ + Black Carbon emissions reductions




*Shindell et al. Science 2012*

# Comparing inventories with atmospheric inversions for anthropogenic methane emissions ( agriculture + fossil )

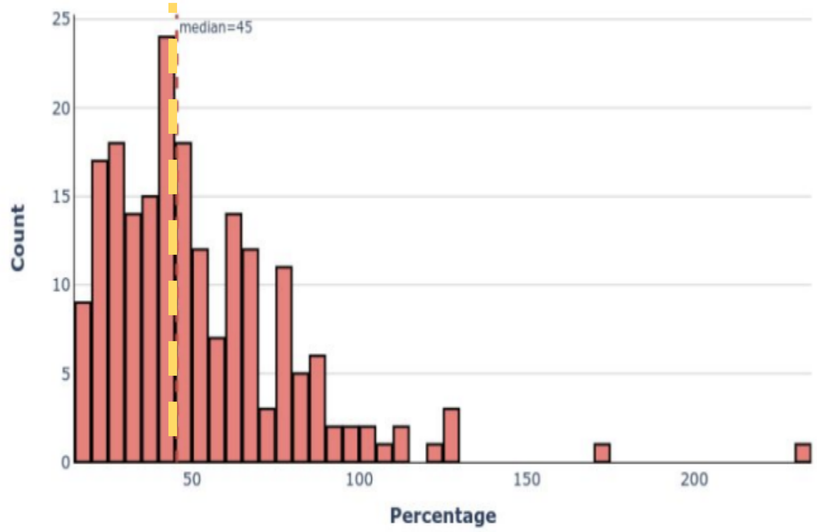


# Satellite detection of methane plumes over fossil fuel production sites and basins

*A low hanging fruit for climate mitigation*

## Uncertainty analysis from sensitivity tests

- Ensemble of quantifications with variations in the main parameters (source location, release duration, background estimation method, wind data, propagation of the error from S5P)
- Median relative uncertainty: 45%




## Descriptive statistics of the plumes

- 2500 single observed events since 2019
- Very large leaks > 20 $tCH_4\ h^{-1}$ systematically detected & quantified using TROPOMI