SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	…2026………………………………………………………………
Project Title:	Global emissions of methane inferred from atmospheric inversions modelling technique …………………………………………………………………
Computer Project Account:	**SP** ECJRC …………………………………………………………………
Principal Investigator(s):	…Francesco Graziosi ……………………………………………………………… …………………………………………………………………
Affiliation:	European Commission, Joint Research Centre (EC-JRC) ………………………………………………………………
Name of ECMWF scientist(s) collaborating to the project (if applicable)	………………………………………………………………… …………………………………………………………………
Start date of the project:	01/01/2025…………………………………………………… ……………
Expected end date:	31/12/2028…………………………………………………… ………

Computer resources allocated/used for the current year and the previous one
(if applicable)
Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	900.000	80.000	900.000	150.000
Data storage capacity	(Gbytes)	2500	1500	2500	200

Summary of project objectives (10 lines max)

The aim of the project is to determine global methane fluxes over multiannual analysis using an inverse modeling system. This system is based on the TM5-MP chemical transport model, four-dimensional variational data assimilation inverse modeling, and atmospheric observations. Additionally, the project's purpose is to analyze the relationship between natural parameters, such as temperature and precipitation, and methane fluxes over wetland areas.

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Summary of problems encountered (10 lines max)

No significant problems were encountered.

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Summary of plans for the continuation of the project (10 lines max)

The next steps will be to increase the resolution up to 1 x 1 degree resolution using surface based and TROPOMI satellite. Moreover, increase the number of surface-based concentrations, covering the Asian domain. Improve the analysis of emission response of physical parameters such as surface and soil temperatures, precipitation, water soil contents retrieved from ERA 5 dataset.

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List of publications/reports from the project with complete references

Graziosi, F., Manca, G., Segato, D., Dobricic, S., and Arriga, N.: Inverse modelling of global CH4 emissions using surface based measurements and GOSAT satellites retrievals., EGU General Assembly 2025, Vienna, Austria, 27 Apr–2 May 2025, EGU25-15454, https://doi.org/10.5194/egusphere-egu25-15454, 2025.………………………………………………………………………………………………………
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Summary of results

Introduction

This assessment aims to quantify the response of methane (CH_4) emissions to climate variability, with a particular focus on emissions from natural wetlands. Wetlands are the largest natural source of atmospheric methane, accounting for approximately one-third of global CH_4 emissions. However, substantial uncertainties remain in estimating wetland methane fluxes, posing a major challenge to accurately constraining the global methane budget and its response to climate change. Methane production in wetlands is primarily driven by microbial methanogenesis under anaerobic soil conditions. The rate of methanogenesis depends on several interacting environmental factors, including soil temperature, water-table depth, and the quality and quantity of available organic matter. Temperature regulates microbial activity and decomposition rates, while water-table fluctuations determine the extent of oxygen-limited conditions required for methane production. Organic matter provides the substrate for methanogenic microorganisms, linking ecosystem productivity to methane emissions.

Climate change is expected to influence each of these key controls through increasing temperatures, altered precipitation regimes, changes in hydrological conditions, and shifts in vegetation productivity. Consequently, both the magnitude and spatial distribution of wetland methane emissions are likely to change over the coming decades. Improving our understanding of the sensitivity of wetland methane emissions to these climatic drivers is therefore essential for reducing uncertainties in future methane projections and for better representing wetland processes in Earth system models.

Methodology

The inversions were conducted using the TM5-4DVAR inverse model system from the years 2018 to 2021. The model was driven by ECMWF-ERA5 meteorological data at a resolution of 1° x 1° for both latitude and longitude and encompasses 137 vertical levels. The methane fluxes were optimized using high-resolution surface-based measurements from the NOAA Earth System Research Laboratory (ESRL) global cooperative air sampling network, as well as column-averaged dry mixing ratio XCH_4 data from the GOSAT satellite. This four-dimensional inverse system generates monthly global fields of CH_4 fluxes across four source categories: wetlands, rice fields, biomass burning, and anthropogenic activities. Here, we focus on determining methane emissions from wetlands and their sensitivity to climate variables. We analysed the emission response to 2 m temperature (T) and total precipitation (P) based on ECMWF-ERA5 reanalysis. We considered four climate zones based on the Köppen-Geiger classification: boreal, temperate, equatorial, and arid.

Results

The atmospheric inversion estimates a mean global wetland methane emission of **188 Tg CH_4 yr^{-1}** for the period 2018–2021. As shown in **Figure 1**, approximately **60% of the total wetland emissions originate from tropical regions**, confirming the dominant contribution of tropical wetlands to the global natural methane budget. Boreal and temperate wetlands together contribute approximately **35%** of the global emissions, while arid regions account for only a minor fraction due to their limited wetland extent.

To investigate the climatic controls on wetland methane emissions, the optimized monthly emissions were analysed against ERA5 2 m air temperature and total precipitation within four Köppen–Geiger climate zones: boreal, temperate, equatorial, and arid. The resulting bidimensional response functions (**Figure 2**) reveal distinct climate sensitivities across the different regions. Consistent with the findings of Koffi et al. (2020), boreal wetlands exhibit a strong dependence on temperature. High methane emissions are concentrated at warmer temperatures, indicating that microbial methanogenesis in cold regions is primarily temperature-limited. As temperatures increase during the growing season, enhanced microbial activity and longer thaw periods promote greater methane production.

In contrast, tropical wetlands display a much stronger sensitivity to precipitation than to temperature. Since temperatures remain favourable for methanogenesis throughout the year, changes in rainfall and the associated water-table dynamics become the dominant controls on methane emissions. Periods of increased precipitation promote saturated soil conditions, creating the anaerobic environment required for methane production, whereas reduced precipitation lowers water tables and suppresses emissions. This behaviour is clearly visible in **Figure 2**, where the highest tropical emissions are associated with increasing precipitation rather than temperature.

The temperate and boreal regions, representing approximately one-third of global wetland methane emissions, exhibit an approximately linear increase in methane emissions with both temperature and precipitation. This combined sensitivity suggests that future warming, together with projected changes in regional hydrology, could substantially enhance methane emissions from higher-latitude wetlands. As these regions are expected to experience some of the largest climatic changes during the coming decades, they may become increasingly important contributors to the global methane budget.

Overall, the inversion results demonstrate that the climatic controls on wetland methane emissions vary substantially among climate zones (**Figure 2**). Temperature is the dominant driver in cold regions, whereas precipitation plays the primary role in tropical wetlands. Together with the regional emission distribution shown in **Figure 1**, these findings provide important observational constraints for improving process-based wetland methane models and reducing uncertainties in future projections of the global methane budget under changing climate conditions.

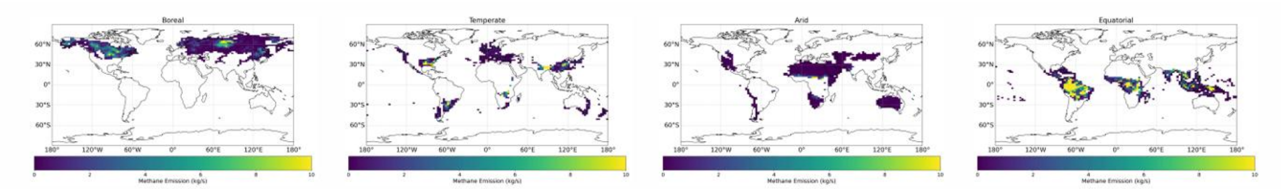

Figure 1. Global Methane Wetland emissions distribution across four climate areas

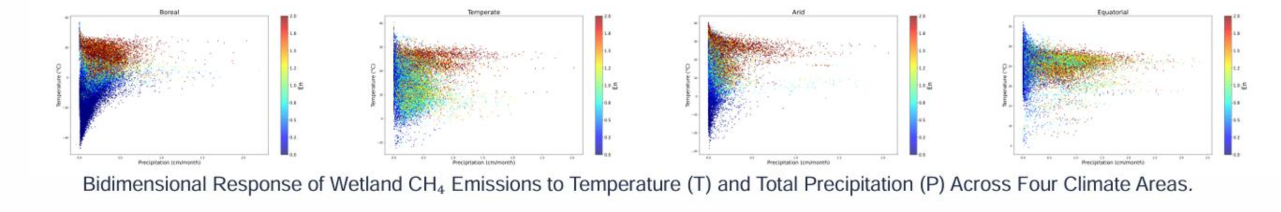

Figure 2. Bidimensional response of wetland CH4 emissions to Temperatiure (T) and Total Precipitation (P) Across four climate Areas.

Reference: Ernest N. Koffi et al.,An observation-constrained assessment of the climate sensitivity and future trajectories of wetland methane emissions.Sci.Adv.6,eaay4444(2020).DOI:10.1126/sciadv.aay4444