

INVITED COMMENTARY

Methane release from tidal wetlands

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Tidal wetlands are widely distributed along the world's coastlines, covering at least 354,600 km² (Murray et al., 2022). As a transitional zone between terrestrial and marine ecosystems, tidal wetlands provide many critical ecosystem services, including carbon sequestration and storage, biodiversity conservation, coastal erosion reduction, fisheries support, and water quality improvement.

The slow decomposition of organic matter in submerged anoxic sediments is conducive to the accumulation of large amounts of soil organic carbon, known as blue carbon, in tidal wetlands. However, the anaerobic conditions that promote soil carbon storage in tidal wetlands also lead to microbial methane (CH₄) production. CH₄ is a potent and long-lived greenhouse gas, second only to carbon dioxide in induced warming since the Industrial Revolution. CH₄ emissions in tidal wetlands are highly variable in time and space due to diverse habitats and complex confounding effects. For example, annual CH₄ emissions from tidal flats, salt marshes, and mangroves are estimated to be 2.00 ± 1.51, 1.46 ± 0.91, and 4.2 ± 4.9 Tg CH₄ per year, respectively, based on bottom-up approaches (Rosentreter et al., 2021). The large uncertainty in global tidal wetland CH₄ emissions is mainly due to incomplete observational data and limited knowledge of the controlling mechanism of CH₄ flux variation at different temporal scales from different ecosystems. Therefore, it is important to gain a more comprehensive understanding of the methane fluxes in tidal wetlands.

Recently, Arias-Ortiz et al. (2024) compiled a comprehensive data set of chamber-based CH₄ flux measurements across tidal marshes in the contiguous United States (CONUS), including 122 tidal marsh sites accompanied by complementary porewater biogeochemistry data. The data set itself in this study is an important contribution to the ecosystem methane flux community, which is very helpful in determining the complex responses of methane flux to different biogeochemical variables and improving predictions of CH₄ release in these

ecosystems. Based on this data set, the authors found that the dominant factors contributing to methane vary with spatiotemporal scales across tidal wetlands. At the spatial scale (across sites), salinity dominated over other factors, and annual CH₄ emissions decreased with increasing salinity. At the temporal scale, variations in CH₄ flux were mainly influenced by temperature, gross primary productivity, and tides at the seasonal scale, while the diel dynamics of CH₄ flux were mainly controlled by plant activity. The widespread scale-dependent responses of CH₄ flux to biogeochemical controls in tidal wetlands are consistent with previous findings in some inland wetlands and uplands (Chen et al., 2019; Knox et al., 2021). In those studies, temperature is often the primary driver of seasonal changes in CH₄ flux changes, but transport-related factors can become predominant at diurnal scales.

Arias-Ortiz et al. (2024) provide new insights into how CH₄ emissions in tidal wetlands are regulated by different environmental factors at different scales, with important implications for modeling studies. Earth system models need to consider more realistic combinations of biogeochemical effects and mechanisms to better simulate the future of CH₄ release from tidal wetlands in a changing climate. First, as shown by Arias-Ortiz et al. (2024), the determinants of CH₄ flux in tidal wetlands are highly scale-dependent and vary significantly from diel to seasonal scales. Therefore, different biogeochemical pathways should be applied when establishing CH₄ emission models at different temporal scales. Furthermore, lagged relationships (e.g., between plant productivity and CH₄ flux) and multivariate interactions are common in regulating CH₄ emissions from tidal wetlands (Arias-Ortiz et al., 2024; Hill et al., 2024) and should be considered in models. However, it is worth noting that the hysteretic relationship between plant productivity and CH₄ flux may be caused by confounding effects of environmental factors rather than substrate supply (Chen et al., 2020).

Arias-Ortiz et al. (2024) have opened new research directions in this field. First, it is essential to clarify the interactive effects of different biotic and abiotic variables, as these factors always covary in real ecosystems. The variation of CH₄ emissions in tidal wetlands is determined by several complex processes, such as CH₄ production by methanogens, CH₄ oxidation by methanotrophs, and CH₄ transport through plants, diffusion, or ebullition. These processes are influenced by the interactions of different impacting factors. Arias-Ortiz et al. (2024) provide a good example of the interaction between salinity and temperature. At salinities >18psu, CH₄ fluxes were consistently low regardless of temperature, whereas at salinities <18psu, CH₄ fluxes increased with long-term mean annual maximum daily temperature. A previous study also reported that the temperature responses of CH₄ fluxes in wetlands were regulated by water table depth (Chen et al., 2021). Thus, more interactions and the underlying mechanisms need to be further elucidated in future research.

Next, the impact of human activities on methane fluxes in tidal wetlands should not be ignored. Tidal wetlands are vulnerable to human activities such as accelerated sea level rise, artificial barriers to inland wetland migration, drainage and conversion to agriculture, and overuse of fertilizers. These anthropogenic disturbances and climate change may interact to produce more complex effects on methane emissions from tidal wetlands. For example, sea level rise and inhibited inland migration may increase the water table depth and limit sediment organic matter accumulation rates, which regulate the relative increase in tidal wetland CH₄ and CO₂ emissions under future global warming (Chen et al., 2021; Hu et al., 2024).

In addition, plant functional traits associated with methane flux in tidal wetlands need to be further investigated in future studies. Plants significantly affect CH₄ emissions in wetlands by providing substrate for CH₄ production and transporting CH₄ through aerenchymatic tissues. Arias-Ortiz et al. (2024) also highlighted the effects of plant activity on CH₄ fluxes at different time scales and sites. In this study, they used gross primary production, net ecosystem exchange, and latent heat to represent plant activity. It is possible that traits related to photosynthesis and aeration play important roles in regulating CH₄ fluxes in tidal wetlands, but this remains unclear. Understanding the links between these related plant functional traits and ecosystem-scale methane flux dynamics can help to improve estimates of CH₄ emissions from tidal wetlands.

It is critical to accurately determine CH₄ emissions from tidal wetlands in a changing climate. Tidal wetlands are distinctive ecosystems with highly diverse species composition and complex, flexible environments. Therefore, CH₄ emissions from tidal wetlands may have different emergent properties compared to those from freshwater wetlands. This study provides a very valuable data set to further explore the patterns, responses, and adaptation of CH₄ fluxes in different tidal wetland ecosystems. We look forward to future research to further explore the unique processes and mechanisms of methane emissions in tidal wetlands in the future.

AUTHOR CONTRIBUTIONS

Weinan Chen: Conceptualization; writing – original draft. **Yiqi Luo:** Writing – review and editing. **Shuli Niu:** Conceptualization.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no data sets were generated or analyzed for the current article.

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