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Transient attribution of global lake methane emissions

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The methane (CH_4) emissions from lakes were considered entirely natural by the Intergovernmental Panel on Climate Change (IPCC) and Global Methane Budget (Saunois *et al.*, 2020). However, total phosphorus (TP) are substantial control factors of both diffusive and ebullitive CH_4 fluxes, indicating a fraction of these emissions attributable to human factors. Here, we adopted a newly developed process-based model, FLaMe-v1.0 (Fluxes of Lake Methane), to decompose the bulk emissions into natural and anthropogenic components. By configurating global lakes from HydroLAKES database (with an area of 2.47 million km^2), we estimated the global lake CH_4 emissions as 33±1 Tg CH_4 yr^{-1} during 1900s and 40±1 Tg CH_4 yr^{-1} during 1990s, suggesting a 21% increase over last century. Furthermore, we adopted a factorial experiment approach to conduct the attribution analysis, and found that eutrophication (or TP) and climate contribute to 73% and 27% of the accumulated growth of global lake CH_4 emissions, respectively. Moreover, we identified a progressive shift from eutrophication to climate control on global lake CH_4 emissions from early stage to the end of last century. In the future, we projected the global lake CH_4 emissions by 2070 to be 43±2, 48±3 and 47±3 Tg CH_4 yr^{-1} under SSP1-2.6, SSP3-7.0 and SSP5-8.5, respectively. Our analysis implies that the future risks stemming from lake CH_4 emissions could be greatly reduced by efficient nutrient removal from urban and agricultural sources.