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Freshwater methane emissions offset the continental carbon sink

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Abstract

Inland waters (lakes, reservoirs, streams and rivers) are often substantial methane (CH_4) sources in the terrestrial landscape. They are, however, not yet well integrated in global greenhouse gas (GHG) budgets. Data from 474 freshwater ecosystems and the most recent global water area estimates indicate that freshwaters emit at least 103 Tg of CH_4 yr^{-1} corresponding to 0.65 Pg C as CO_2 equivalents yr^{-1}, offsetting 25% of the estimated land carbon sink. Thus, the continental GHG sink may be considerably overestimated and freshwaters need to be recognized as important in the global carbon cycle.

A cornerstone of our understanding of the contemporary global carbon cycle is that the terrestrial land surface is an important greenhouse gas (GHG) sink (*1, 2*). The global land sink is estimated to be 2.6 ± 1.7 Pg C yr^{-1} (excluding C emissions due to deforestation) (*1*). Lakes, impoundments, and rivers are parts of the terrestrial landscape but they have not yet been included in the terrestrial GHG balance (*3, 4*). Available data suggest, however, that freshwaters can be substantial sources of CO_2 (*3, 5*) and CH_4 (*6*). Over time, soil carbon reaches freshwaters by lateral hydrological transport where it can meet several fates including burial in sediments, further transport to the sea, or evasion to the atmosphere as CO_2 or CH_4 (*7*). CH_4 emissions may be small in terms of carbon, but CH_4 is a more potent GHG than CO_2, over century timescales. This study indicates that global CH_4 emissions expressed as CO_2 equivalents correspond to at least 25 % of the estimated terrestrial GHG sink.

CH_4 can be emitted from freshwaters through several different pathways, including ebullition (bubble flux from sediments), diffusive flux, and plant-mediated transport through emergent aquatic plants (*6*). Additional pathways may be important for hydroelectric reservoirs such as emissions upon passage through turbines and downstream of reservoirs (*8, 9*). We compiled CH_4 emission estimates from 474 freshwater ecosystems for which the emission pathways were clearly defined (Table 1, *10*).

Using recent data on the area and distribution of inland waters (*11, 12*), we estimate the total CH_4 emission from freshwaters to 103 Tg CH_4 yr^{-1} (Table 1). Expressed as CO_2 equivalents this corresponds to 0.65 Pg C (CO_2 eq) yr^{-1} or 25% of the estimated land GHG sink, assuming that 1 kg CH_4 corresponds to 25 kg CO_2 over a 100-year period (*13*). Ebullition and plant flux, which are both poorly represented in the data set, dominate the other flux pathways which have been studied more frequently (Table 1). Ebullition is most likely to be underestimated because it is episodic and not representatively captured by the usual short term measurements (*6*). Accordingly, our global estimate of freshwater CH_4 emissions is probably conservative. For further discussion of the results see supporting online text.

Altogether this study indicates that CH_4 emissions from freshwaters can substantially affect the global land GHG sink estimate. Moreover, proper consideration of ebullition and plant mediated emission will most likely result in increased future estimates of CH_4 emission. Combining the present CH_4 emission estimate of 0.65 Pg C (CO_2 eq) yr^{-1} with the most recent estimate of freshwater CO_2 emissions, 1.4 Pg C (CO_2 eq) yr^{-1} (*5*) – together corresponding to 79 % of the estimated land GHG sink – it becomes clear that freshwaters are an important component of the continental GHG balance. Accordingly, the terrestrial GHG sink may be smaller than currently believed and data on GHG release from inland waters are needed in future revision of net continental GHG fluxes.

References and Notes

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Supporting Online Material

www.sciencemag.org

Materials and Methods

Supporting text

Supporting References and Notes

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Table 1. Freshwater CH_4 emissions estimated from average areal estimates (flux m^{-2} yr^{-1}) times the areal estimates for different latitudes (*10*). "Tot open water" is the sum of open water fluxes, i.e. ebullition (Ebul), diffusive flux (Diff), and flux when CH_4 stored in the water column is emitted upon lake over turn (Stor), respectively. *n* and *CV* denotes the sample size (number of systems) and the coefficient of variation. Note the small sample size for many large emission values. The total sums of the yearly fluxes are expressed in Tg CH_4.

Type and latitude	**Emission Tg CH_4 yr^{-1}**												**Area[a] km²**
	Tot open water	*n*	*CV %*	**Ebul**	*n*	*CV %*	**Diff**	*n*	*CV %*	**Stor**	*n*	*CV %*	
Lakes													
>66	6.8	*17*	*72*	6.4	*17*	*74*	0.7	*60*	*37*				288318
>54-66	6.6	*5*	*155*	9.1	*9*	*60*	1.1	*271*	*185*	0.1	*217*	*2649*	1533084
25-54	31.6	*15*	*127*	15.8	*15*	*177*	4.8	*33*	*277*	3.7	*36*	*125*	1330264
<24	26.6	*29*	*51*	22.2	*28*	*54*	3.1	*29*	*97*	21.3	*1*		585536[b]
Reservoirs													
>66	0.2[c]												35289
>54-66	1.0	*24*	*176*	1.8	*2*	*140*	0.2	*4*	*93*				161352
25-54	0.7[d]												116922
<24	18.1	*11*	*87*										186437
Rivers													
>66	0.1	*1*											38895
>54-66	0.2[c]												80009
25-54	0.3	*20*	*302*										61867
<24	0.9[d]												176856
Sum open water	93.1	*116*		55.3	*59*		9.9	*343*		25.1	*254*		
Plant flux[e]	10.2												
Sum all	104												

[a] Lake and river area from (*11*). Reservoir area from (*12*),
[b] Likely underestimated – for comparison the mean flooded area for the major South American savanna wetlands) and the lowland Amazon (below 500 m.a.s.) is 115 620 km² and 750 000 km², respectively (*14*).
[c] Estimated assuming similar emissions per area unit at latitudes > 54 degrees.
[d] Estimated assuming similar emissions per area unit at latitudes from 0 to 54 degrees.
[e] Plant flux (plant mediated emission) according to (*10*).