Models for annual averages of methane ebbulitive and diffusive emissions from hydroelectric reservoirs

Based on data from the Furnas Carbon Budget Program

presented by

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Objective: build merit-weighted models to predict methane (CH_4) release rates from hydroelectric reservoirs based on annual averages of parameters such as total carbon (TC) in river water [mg C L^{-1}], reservoir age [months], 10 cm deep “surface” water temperature [°C], air temperature [°C], water residence time [days] and water surface altitude [m a.s.l.].

Outcome: models calculated with data from latitudes higher than 14°S.

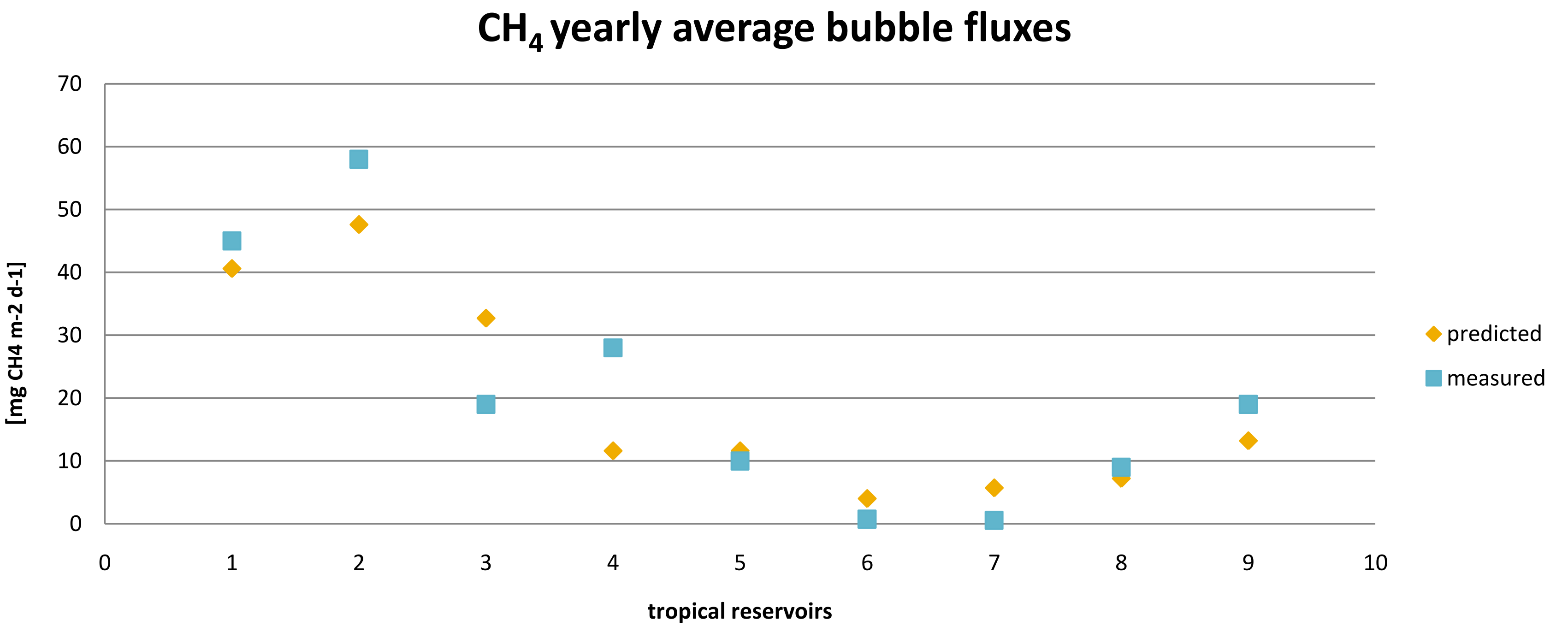
Model utilization example: a model is used to predict CH_4 annual average diffusive emission from a hydroelectric reservoir at latitude 47°N.

Ebbulitive CH_4 emission model is

$$y_{[\text{mg CH4 m-2 d-1}]}=0.161e^{0.32x[\text{mg C L-1}]}+15.68e^{-0.006x[\text{months}]}+5E\text{-}09e^{0.74x[\text{surf.wat.°C}]}+1.305\ln x_{[\text{days}]}+46.26e^{-0.006x[\text{m a.s.l.}]}-2.805$$

Predictive capability range (PCR) for this ebbulitive model is 176%.

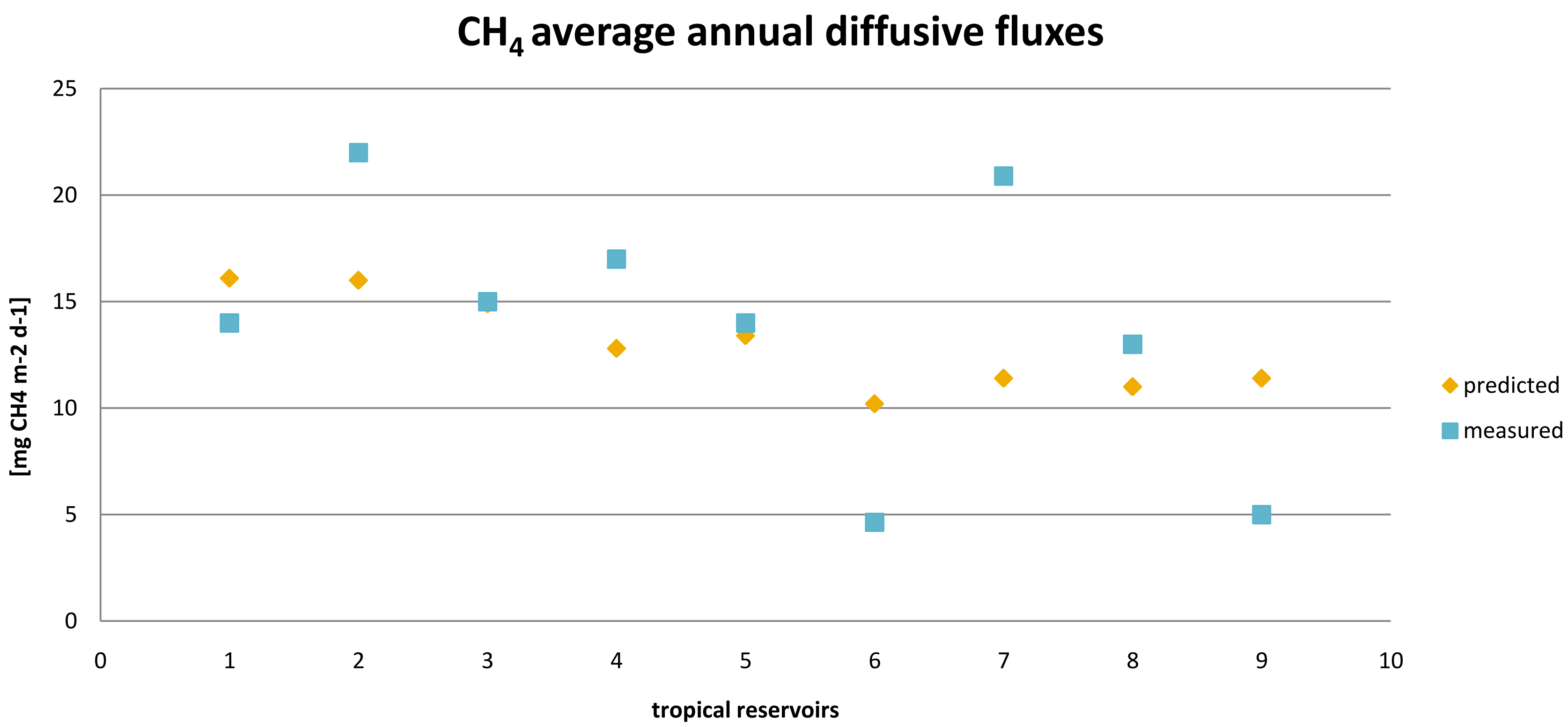
PCR is defined as the average of absolute values of individual deviations, expressed in per cent, of predicted from measured emissions



Diffusive CH_4 emission model is

$$y_{[\text{mg CH4 m-2 d-1}]} = 0.796\ln x_{[\text{mg C L-1}]} - 0.596\ln x_{[\text{months}]} + 0.0226e^{0.18x[\text{surf.wat.°C}]} + 0.004e^{0.22x[\text{air temp.°C}]} + 0.341\ln x_{[\text{days}]} + 8.174$$

PCR for this diffusive model is 42%



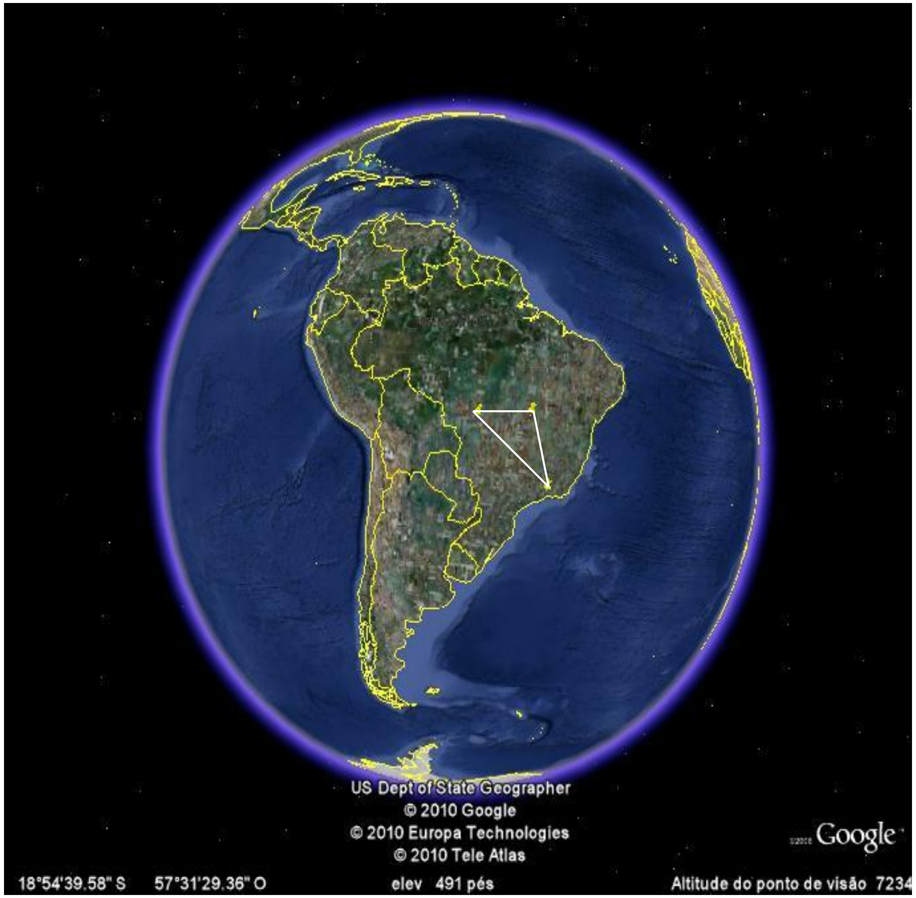
An example of model utilization to predict CH_4 average annual diffusive emission from 1080 month-old hydroelectric run-of-river reservoir at latitude 47°N with total organic carbon (TOC)† inflow ~ 2.4 mg L^{-1},water temperature between ~ 5°C in winter to ~ 20°C in summer (average 12.5°C, also assumed for air) and residence time ~ 2 days.

... run Diffusive CH_4 Average Annual Emission **model ...**

Predicted diffusive emission: **5.2** mg CH_4 m^{-2} d^{-1}
Average of diffusive emissions directly measured (during summer of July 2008 – not during one whole year) with anchored floating chambers:
12±7 (min 7; max 30; n=19) mg CH_4 m^{-2} d^{-1} (Del Sontro *et al.* 2010).

Therefore, the predicted average annual diffusive emission (5.2) is similar to the smallest emission (7) measured during summer.

Model calculation with data from Furnas Carbon Budget Program



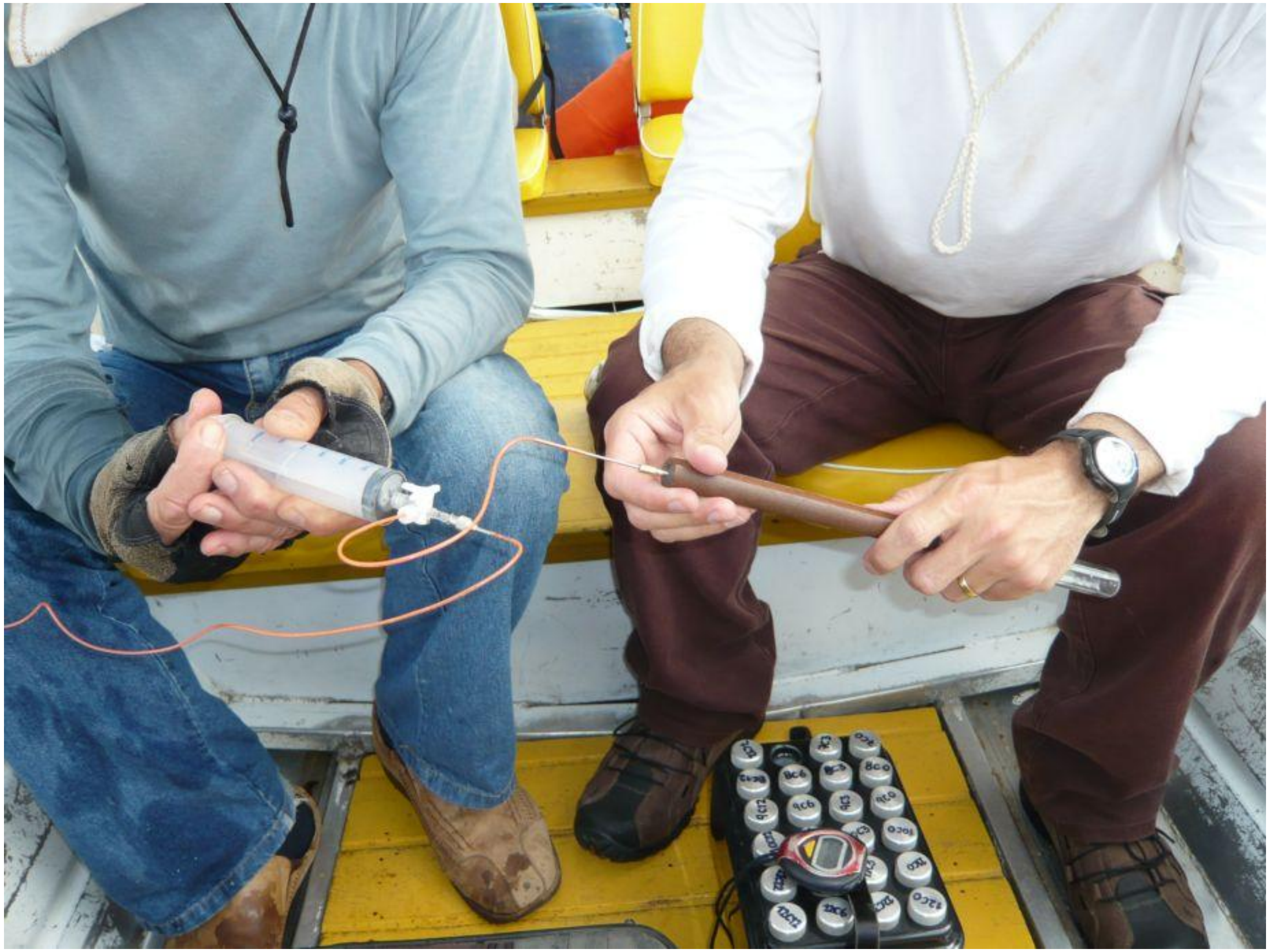
Between years 2003 and 2007, 8 Brazilian reservoirs located between longitudes 44°W and 55°W and latitudes 14°S and 22°S were surveyed by 4 teams, 3 times each reservoir, within a one- year period. Two years later the most recent of the 8 reservoirs was again surveyed 3 times in a one-year period.

The Federal University of Rio de Janeiro/COPPE team measured methane emissions from 15 to 56 representative sites per survey, distributed among dendritic and main body areas of each of the 8 reservoirs to obtain significant spatial coverage during each of the 3 seasonal surveys.

Funnels collected ebbulitive fluxes

Chambers sampled diffusive fluxes

Gas samples were stored in glass ampoules and taken for chromatographic analyses at a portable lab assembled for field surveys



Chromatographic analyses field laboratory

Averages of:

measured ebbulitive and diffusive emissions [mg CH_4 m^{-2} d^{-1}] ,

C in inflowing river waters [mg C L^{-1}],

air and surface water temperature [°C] and

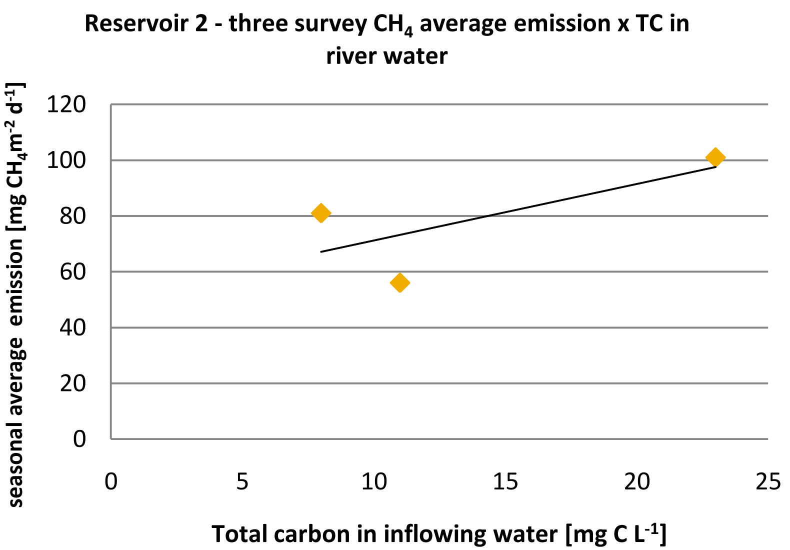
water surface elevation [m a.s.l.]

were calculated after each survey.

While studying the data for the model calculation we observed that the 3 seasonal survey averages of emissions when plotted against other parameter averages (e.g. TC in river water) although not always sufficient to confirm correlation tendencies, can supply hints about correlation tendencies.

Example of correlation hint: correlation coefficient *r*=+0.7 between total CH_4 emission and TC in river water suggests positive correlation between CH_4 emission and TC

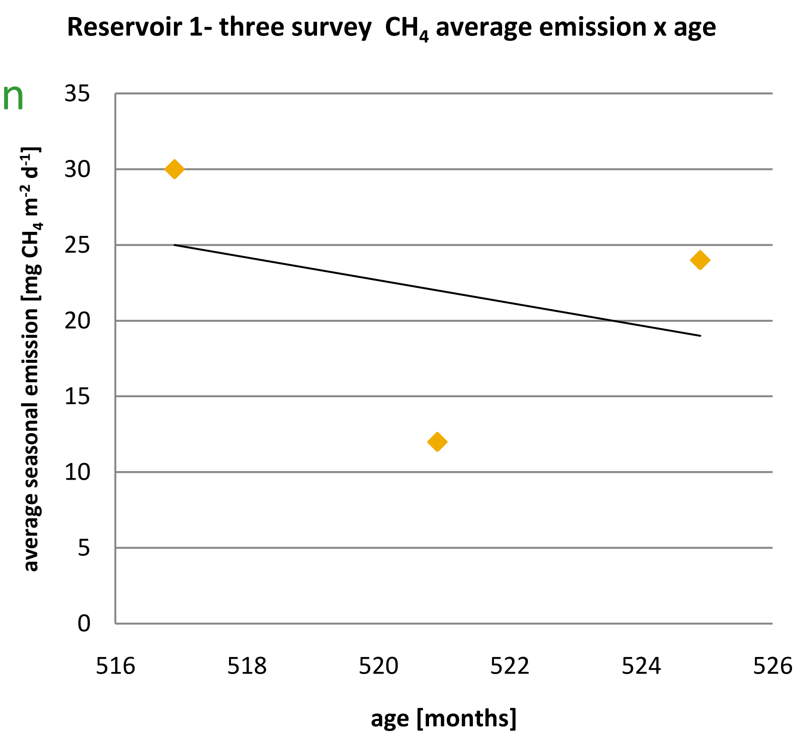
Table with averages of 3 field campaigns at Reservoir 2	Total diffusive plus ebbulitive emission average [mg CH_4 m^{-2} d^{-1}]	Total carbon (TC) average in river water [mg C L^{-1}]
Reservoir 2 Survey 11/03	101 (n=18+11)	23 (n=7)
2 -03/04	81 (n=11+15)	8 (n=14)
2-07/04	56 (n=16+23)	11 (n=15)



A further example of correlation hint: correlation coefficient *r*=-0.3 between total CH_4 emission and reservoir age suggests a tendency towards negative correlation between CH_4 emission and reservoir age.

CH_4 emission

Table with averages of 3 field campaigns at Reservoir 7	Total diffusive plus ebbulitive emission average [mg CH_4 m^{-2} d^{-1}]	Reservoir age [months]
Reservoir 7 Survey 11/05	30 (n=30+15)	516.9
7 -04/06	12 (n=28+20)	520.9
7-08/06	24 (n=27+29)	524.9



Then, ebbulitive and diffusive CH_4 average **annual** emissions - averaged over the 3 seasonal surveys - were plotted against (also averaged over the 3 seasonal surveys) TC in river water [mg C L^{-1}] ; reservoir age [months] ; surface water temperature [°C] at about 10 cm depth; air temperature [°C] at ~ 1 m above water surface; residence time [days] and water surface altitude [m a.s.l.].

Tendencies were confirmed as data input increased

Reservoir	Correlation coefficient (*r*) between 3 seasonal survey averages of total CH_4 emission (diffusive + ebbulitive) against reservoir age
1	-0.7 (n=51+72)
2 (2003/2004)	-1 (n=45+49)
2 (2006/2007)	-1 (n=34+30)
3	+0.8 (n=55+36)
4	-0.9 (n=77+30)
5	-1 (n=37+38)
6	+0.8 (n=55+34)
7	-0.3 (n=85+64)
8	-1 (n=30+27)

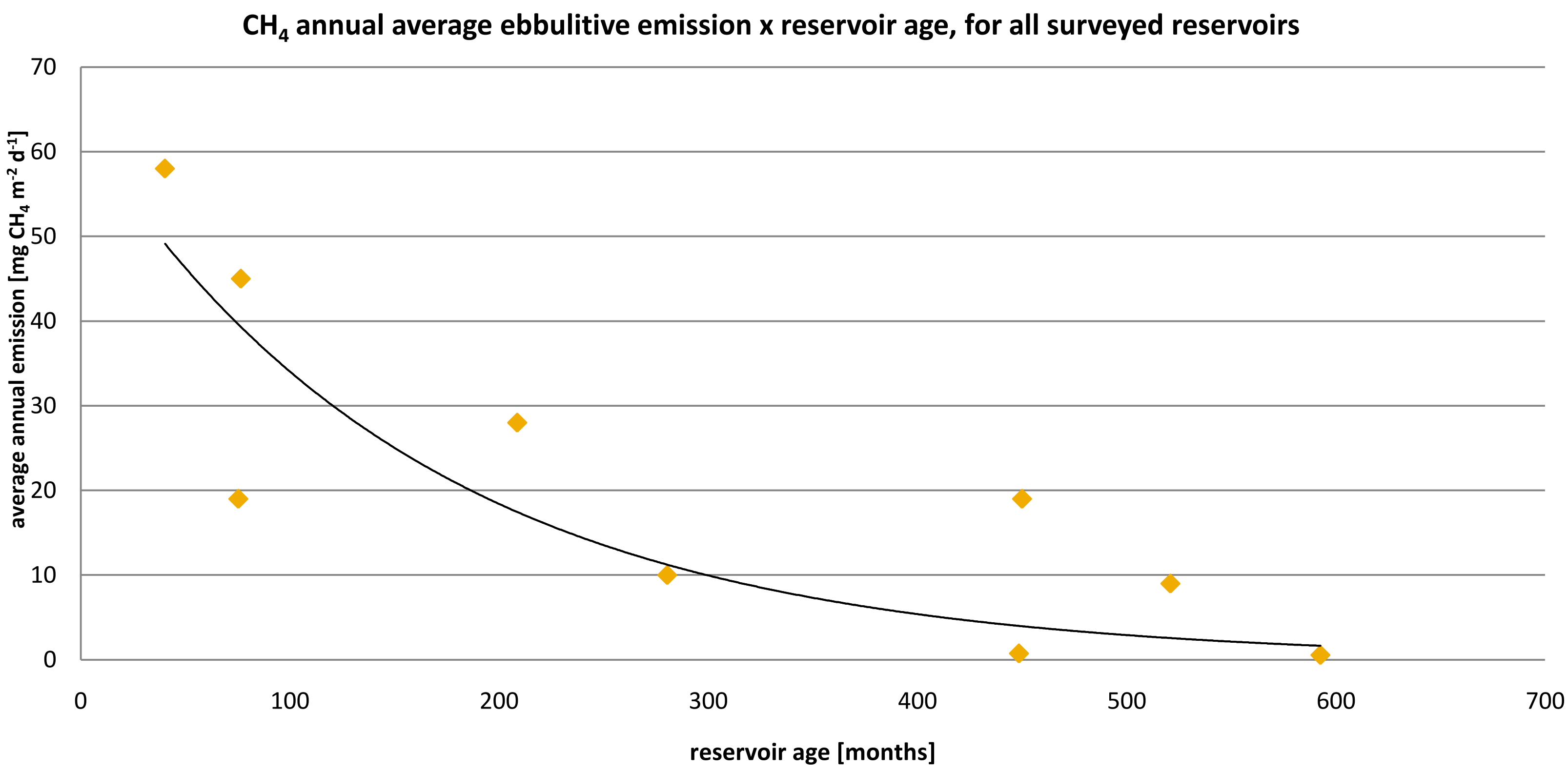
Example of confirmed tendency:

CH_4 emissions decrease with age

supported by a two-sided nonparametric statistics Sign Test (2 positive *vs.* 7 negative *r* signs; N=9) at the $\alpha = 2(0.09) = 0.18$ level of significance, which allows rejection of null hypothesis.

Null hypothesis is that there are as many positive signs as there are negative signs, in other words, no tendency observed.

$y_{[mg\ CH4\ m\text{-}2\ d\text{-}1]}=62.954e^{-0.006x[months]}$ is an example of exponential fit with coefficient of determination R^2=0.6



Parameters presenting fits with higher coefficients of determination (bold figures in table below) were selected for calculation of emission models. Example of accepted parameters: TC in river water for both ebbulitive and diffusive emission models. Example of rejected parameters: air temperature (R^2=0.0067) for the ebbulitive emission model as well as surface water altitude (R^2=0.060) for the diffusive emission model.

Emission	TC in river	Age	Surface water temperature	Air temp. 1 m above water surface	Residence time	Altitude
bubbles	**0.57**	**0.60**	**0.40**	0.0067	**0.40**	**0.44**
diffusion	**0.16**	**0.20**	**0.21**	**0.17**	**0.19**	0.060

Merit factor of each parameter for both types of CH_4 emission, is shown in table below. None-zero merit factors are proportional to coefficients of determination.

CH_4 emission models are a sum of parcels, where each parcel is a fit equation multiplied by its respective merit factor.

Example of ebbulitive (= bubbles) model “age” parcel:

$$0.249 \times 62.954e^{-0.006x[\text{months}]}$$

Emission	TC in river	Age	Surface water temperature	Air temp. 1 m above water surface	Residence time	Altitude
bubbles	**0.237**	**0.249**	**0.166**	0	**0.166**	**0.183**
diffusion	**0.172**	**0.215**	**0.226**	**0.183**	**0.204**	0

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