Supplement of

WETMETH 1.0: A new wetland methane model for implementation in Earth system models

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1 Supplementary figures

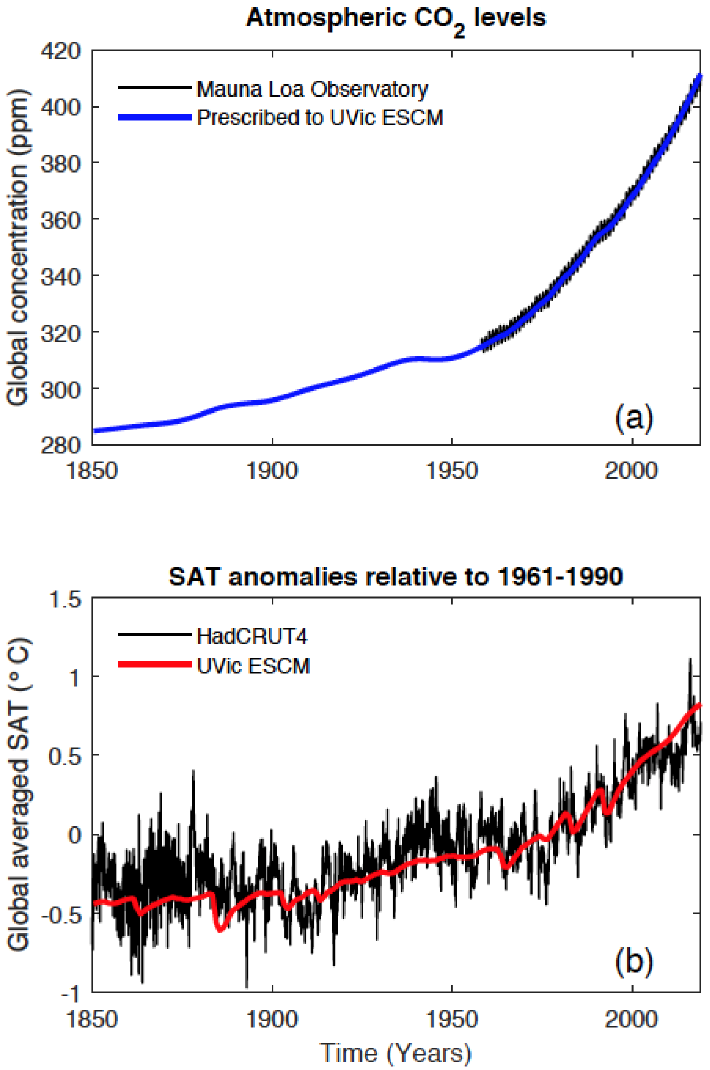

Figure S1: Illustration of the global climate conditions from 1850 through 2019 as simulated by the fully coupled UVic ESCM: (a) Atmospheric CO_2 concentration prescribed to the model in comparison to measurements from the Mauna Loa Observatory. (b) Global surface air temperature (SAT) anomalies relative to 1961-1990 in comparison to the HadCRUT4 dataset.

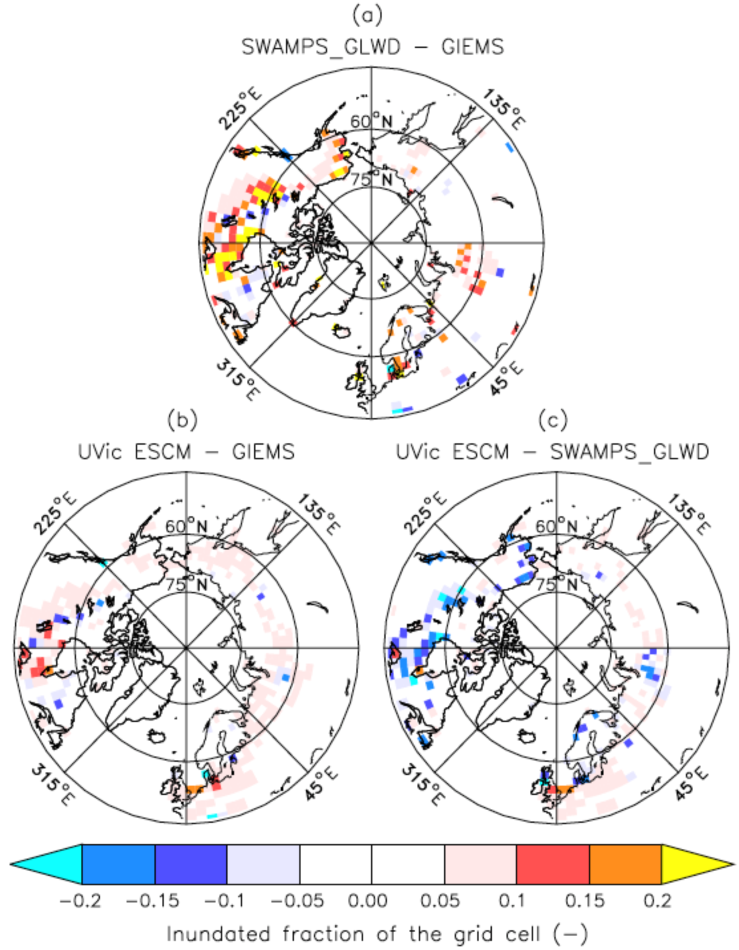

Figure S2: Differences in northern wetland extents (inundated fractions of grid cells) between two datasets (GIEMS and SWAMPS-GLWD) and the UVic ESCM over the 2000-2007 period: (a) SWAMPS-GLWD – GIEMS, (b) UVic ESCM – GIEMS, and (c) UVic ESCM – SWAMPS-GLWD. The comparison period corresponds to the overlap period for the two datasets.

2 Statistical evaluation

2.1 Methods

We consider four metrics to evaluate the model performance with respect to wetland extents and CH_4 emissions: the mean bias error (MBE), the mean absolute error (MAE), the root mean square error (RMSE), and the coefficient of determination (R^2). These metrics allow to compare a set of observations (Y) and their predictions (X) (Ali and Abustan, 2014; Willmott, 1982).

MBE, MAE and RMSE are difference metrics and their respective formulas for a sample size n are given below:

$$\text{MBE} = \frac{1}{n}\sum_{i=1}^{n}(X_i - Y_i) \tag{S1}$$

$$\text{MAE} = \frac{1}{n}\sum_{i=1}^{n}|\,X_i - Y_i\,| \tag{S2}$$

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(X_i - Y_i)^2} \tag{S3}$$

R^2 is a correlation metric from the linear regression theory. It is a measure of the extent to which X predicts the total variability in Y and is given by:

$$R^2 = \frac{\sum_{i=1}^{n}(\hat{Y}_i - \bar{Y})^2}{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}\ , \tag{S4}$$

where $\hat{Y}_i$ is the predicted value of X_i and $\bar{Y}$ is the mean of Y. R^2 varies between 0 and 1, with R^2 ~ 1 (R^2 ~ 0) indicating a strong (weak) linear correlation between X and Y.

For wetland extents, we use two observation-based datasets: GIEMS (Papa et al., 2010; Prigent et al., 2001, 2007, 2012) and SWAMPS-GLWD (Poulter et al., 2017). In each case, we calculate the metrics over grid cells containing wetlands for both the UVic ESCM and the dataset. For wetland CH_4 emissions, we use three upscaled flux measurements (UFMs) from across northern regions (>45°N): RF-DYPTOP, RF-GLWD, and RF-PEATMAT (Peltola et al., 2019). At the global scale, we use three process-based model ensembles: GCP-CH4 (Poulter et al., 2017), WetCHARTs (Bloom et al., 2017), and WETCHIMP (Melton et al., 2013). We calculate the metrics over grid cells in which the UVic ESCM and the UFM or model ensemble both predict CH_4 emissions (positive CH_4 fluxes). We use MATLAB version R2018b for all calculations.

2.2 Results for wetland extents

Results listed in Table S1 show that: (i) wetlands in the UVic ESCM are better simulated across northern regions (>45°N) than at the global scale (e.g. RMSE and R^2), and (ii) the model agrees better with SWAMPS-GLWD than with GIEMS at the regional and global scale (all performance metrics). R^2 values suggest a weak linear correlation between our simulated and the estimated wetland extents globally. However, a previous study argues that R^2 and other correlation-based metrics are not best measures for evaluating the goodness-of-fit of hydrologic and hydroclimatic models as these metrics were found to be over-sensitive to extreme values (outliers) and insensitive to additive and proportional differences between observations and model predictions (Legates and McCabe, 1999). As a reference, our comparison of GIEMS to SWAMPS-GLWD yields R^2 = 0.12 for northern high-latitudes (>45°N) and R^2 = 0.22 for the globe.

Table S1: Statistics for the model performance evaluation with respect to northern (>45°N) and global wetland extents. The UVic ESCM is compared to two global wetland datasets over the 2000-2007 period: GIEMS and SWAMPS-GLWD. Mean annual maximum extents over the same period are shown for reference. *n* represents the number of grid cells used in each comparison.

	Mean annual	Statistical comparison with the UVic ESCM				
	max. extent	*n*	MBE	MAE	RMSE	R^2
	(x 10^6 km^2)	(—)	(km^2)	(km^2)	(km^2)	(—)
Northern (>45°N)						
UVic ESCM	4.76	—	—	—	—	—
GIEMS	3.05	429	787.5	1788.3	2374.7	0.09
SWAMPS-GLWD	4.71	690	-108.9	1712.7	2504.5	0.36
Global						
UVic ESCM	12.57	—	—	—	—	—
GIEMS	9.33	869	1024.9	3681.2	6175.5	0.05
SWAMPS-GLWD	10.59	1395	1124.2	2887.0	4234.1	0.11

The comparison of GIEMS to SWAMPS-GLWD yields MBE = -966.7 km^2; MAE = 1898.9 km^2; RMSE = 3313.3 km^2; and R^2 = 0.12 for wetlands north of 45°N (n = 506). The comparison yields MBE = -65.1 km^2; MAE = 2852.5 km^2; RMSE = 5668.7 km^2; and R^2 = 0.22 for global wetlands (n = 1222).

2.3 Results for wetland methane emissions

Table S2 lists the evaluation statistics for wetland CH_4 emissions. For wetlands north of 45°N, results show that the UVic ESCM has no preferential agreement with one of the three UFMs (all performance metrics). Based on the compared grid cells, however, the UVic ESCM simulates more CH_4 emissions than RF-DYPTOP (MBE > 0) and less CH_4 emissions than RF-GLWD and RF-PEATMAP (MBE < 0). At the global scale, the UVic ESCM compares similarly to the three model ensembles (all performance metrics); although simulated CH_4 emissions are higher than those predicted by the WetCHARTs ensemble (MBE > 0) and lower than those predicted by GCP-CH4 and WETCHIMP ensembles (MBE < 0).

At both the regional and global scale, R^2 values suggest a weak linear correlation between the UVic ESCM and the different UFMs or model ensembles (Table S2). As a reference, the inter-comparison of the UFMs yields R^2 values between 0.1 and 0.4 (0.14 for RF-DYPTOP and RF-GLWD; 0.32 for RF-DYPTOP and RF-PEATMAP; 0.33 for RF-GLWD and RF-PEATMAP). The inter-comparison of the model ensembles yields R^2 values ranging from 0.25 to 0.55 (0.25 for WetCHARTs and WETCHIMP; 0.28 for GCP-CH4 and WETCHIMP; 0.55 for WetCHARTs and GCP-CH4). The highest R^2 value for WetCHARTs and GCP-CH4 may be justified by the fact that the two model ensembles are based on the same wetland dataset (SWAMPS-GLWD) (Bloom et al., 2017; Poulter et al., 2017). However, the comparison of these two model ensembles with respect to wetland CH_4 emission intensities (CH_4 emissions per unit of wetland area) yields a small R^2 value (R^2 < 0.1). In fact, the comparison between the UVic ESCM and the three model ensembles as well as the inter-comparison of the model ensembles all yield small R^2 values (R^2 < 0.1) for both northern and global wetlands. This result suggests that large-scale wetland CH_4 intensities are generally not consistent across process-based models.

Table S2: Statistics for the model performance evaluation with respect to CH_4 emissions from northern (>45°N) and global wetlands. For northern wetland CH_4 emissions, the model is compared to three upscaled flux measurements over the 2013-2014 period: RF-DYPTOP, RF-GLWD and RF-PEATMAP. For global wetland CH_4 emissions, the model is compared to three process-based model ensembles over the 2001-2004 period: GCP-CH4, WetCHARTs and WETCHIMP. Annual mean wetland CH_4 emissions over the same period are shown for reference. *n* represents the number of grid cells used in each comparison.

	Annual mean	Statistical comparison with the UVic ESCM				
	emissions	n	MBE	MAE	RMSE	R^2
	(Tg CH_4 yr^{-1})	(—)	(Tg CH_4 yr^{-1})	(Tg CH_4 yr^{-1})	(Tg CH_4 yr^{-1})	(—)
Northern (>45°N)						
UVic ESCM	33.2	—	—	—	—	—
RF-DYPTOP	30.6 ± 9.2	562	0.0041	0.0433	0.0675	0.14
RF-GLWD	37.6 ± 11.8	370	-0.0379	0.0723	0.1044	0.24
RF-PEATMAP	31.7 ± 9.4	351	-0.0256	0.0531	0.0862	0.20
Global						
UVic ESCM	154.4	—	—	—	—	—
GCP-CH4	160.4 ± 28.1	1219	-0.0007	0.1167	0.2501	0.11
WetCHARTs	147.3 ± 31.6	1388	0.0153	0.1037	0.2342	0.16
WETCHIMP	182.9 ± 43.1	1539	-0.0092	0.1061	0.2220	0.19

The comparison of RF-DYPTOP to RF-GLWD yields MBE = -0.0304 Tg CH_4 yr^{-1}; MAE = 0.0661 Tg CH_4 yr^{-1}; RMSE = 0.1073 Tg CH_4 yr^{-1}; and R^2 = 0.14 (n = 468). The comparison of RF-DYPTOP to RF-PEATMAP yields MBE = -0.0219 Tg CH_4 yr^{-1}; MAE = 0.0575 Tg CH_4 yr^{-1}; RMSE = 0.0846 Tg CH_4 yr^{-1}; and R^2 = 0.32 (n = 365). The comparison of RF-GLWD to RF-PEATMAP yields MBE = 0.0085 Tg CH_4 yr^{-1}; MAE = 0.0677 Tg CH_4 yr^{-1}; RMSE = 0.1023 Tg CH_4 yr^{-1}; and R^2 = 0.33 (n = 266).

The comparison of GCP-CH4 to WetCHARTs yields MBE = 0.0213 Tg CH_4 yr^{-1}; MAE = 0.0641 Tg CH_4 yr^{-1}; RMSE = 0.1735 Tg CH_4 yr^{-1}; and R^2 = 0.55 (n = 1727). The comparison of GCP-CH4 to WETCHIMP yields MBE = -0.0192 Tg CH_4 yr^{-1}; MAE = 0.0991 Tg CH_4 yr^{-1}; RMSE = 0.2433 Tg CH_4 yr^{-1}; and R^2 = 0.28 (n = 1780). The comparison of WetCHARTs to WETCHIMP yields MBE = -0.0304 Tg CH_4 yr^{-1}; MAE = 0.0641 Tg CH_4 yr^{-1}; RMSE = 0.1735 Tg CH_4 yr^{-1}; and R^2 = 0.25 (n = 2103).

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