Interactive comment on "Testing the applicability of neural networks as a gap-filling method using CH$_4$ flux data from high latitude wetlands" *by* S. Dengel et al.

S. Dengel et al.

sigrid.dengel@helsinki.fi

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Reply to the anonymous referee #2: (Corresponding author: Sigrid Dengel) (The answers appear after each of the referee's comment)

The manuscript presents a challenging study on gap-filling of incomplete time series of methane flux measurements. Gap-filling of flux time series is of practical and scientific importance in understanding the gas exchange balance between the atmosphere and ecosystems, in particular for methane. Since methane is a compound which exchange cannot be easily predicted from process-based knowledge, statistical models have been frequently used to establish functional relationship between the controlling

environmental variables and methane exchange. Therefore, neural networks serve as potential and novel approach to gap-fill the methane time series at about hourly time scale by using information on environmental variables. The manuscript provides overview about the current knowledge on methane emission drivers and studies as well as basis knowledge on neural network model and data processing. Although neural networks perform as "black box model", the authors make also good effort to interpret the results in terms of functional dependencies. Neural networks show high performance in predicting the missing flux data from high latitude wetlands based on basic environmental variables. Surprisingly, also high variability and extreme flux events are predicted by the model. Such events are not characteristic to carbon dioxide and water exchange, which makes methane flux time series gap-filling much more challenging.

As demonstrated in the manuscript, the neural network approach shows high potential in becoming widely accepted tool in gap-filling of methane flux time series and other flux series with similar sporadic nature. I can recommend it for publication in ACP after considering the items below.

Specific comments and questions 1. The environmental variables as well as 4 fuzzy sets representing the time of day were used as drivers for predicting CH4 emissions for six sites. It is evident that many environmental variables are highly correlated with time of day, which by itself should not be a direct driver for CH4 fluxes. What is the main reasoning including time of day via those 4 fuzzy sets? The issue is explained in section 2.3 (that it is useful to include fuzzy sets to represent diurnal and seasonal variation to reduce cumulative weight of time) but it does not become clear why it is important to include time of day and if and how much it improves predictability.

Reply: The diurnal effect described in section 2.3 (Pre-processing of data) that should be included along with the seasonal variation in form of fuzzy sets is applied to the data via the transformation of the time of day, hence time of day and diurnal are the same in this context. Furthermore section 2.3 has been extended and more detailed information regarding the transformation of these two temporal parameters given. In the early

stages of the analyses these fuzzy sets were left out (Schmidt et al., 2008 found they did not improve their artificial neural network performance) and the performance of the networks much lower than the current ones where these fuzzy sets were included.

2. P.5, l.23 explains that eddy covariance data from 3 sites were filtered according to u*. Please be more specific about the criteria of filtering because Fig. 3b GAM plots seems to indicate wide range of friction velocity values for these 3 sites. Also because at many sites turbulence conditions indicate the state of coupling of atmospheric layers with surface emissions.

Reply: Section 2.1 (Methane flux and meteorological data) does now also include a description of the u* filtering applied to the Lompolojänkkä and Barrow data and how the threshold had been chosen for the Lompolojänkkä data (for example). Furthermore it does also include a short explanation regarding data filtering at the Kytalyk site. Regarding the generalised additive model (GAM) plots (former Fig. 3,a-c), these have now been removed from the revised manuscript.

3. Consider moving section 2.4 after 2.5 because readers not closely familiar with NN method might get misleading impression that the statistical analysis described in that section is part of NN model.

Reply: Section 2.4 (Statistical Analysis) has now been moved after section 2.5 (Applying artificial neural networks to data) to read "2.4 Applying artificial neural networks to data" and section 2.5 as "Statistical Analysis".

4. P.10, l.2, please make easier to understand for the reader the meaning of scenario with short explanation. Text refers to Figures 4 and 5, which do not directly reveal what are the 3 scenarios per gap length, i.e. in total 3 x 5 gap length scenarios = 15 scenarios in total? What is the meaning of "several neural network iterations" in the figure captions?

Reply: Section 2.4 (Applying artificial neural networks to data) includes now a further

paragraph giving a better description of the 5 (15 (= 5 x 3) scenarios in total tested) applied gap length scenarios. Former Figure 4 and 5 have now been removed and have been replaced with graphs showing only the outcome from the neural network using four neurons only. During each repetition (or run) the network does perform many iterations until it converges and finds the global minimum or until all absolute partial derivatives of the error function were smaller than the given threshold (see section 2.4).

5. P.12, l. 26-27, what do the referred ranges mean for the confidentiality of the prediction, is it the 95% confidentiality range?

Reply: This sentence has become redundant and has been removed from the revised manuscript.

6. General question: are all plots in Figures 4 and 5 informative? Consider reducing and keeping only a few plots as the best examples. In turn it would be interesting to summarize and possibly discuss more different functional dependencies of fluxes at 6 different sites as revealed by the statistical analysis and GAM (as presented by Fig. 3).

Reply: Former Figure 4 and 5 have been removed and have now been replaced with graphs showing only the outcome from the neural network using four neurons only. This gave us the possibility to present the data with better clarity, summarising the correlation coefficients and the RMSE (in true physical units now) for a better overview. The entire section regarding the application of the generalised additive model (GAM) has been removed from the revised manuscript. As the model was not used for driver selection but as a "verification" of the pre-selected drivers (input variables) it appeared somehow out of context. Their use does not add extra useful information to our artificial neural networks, so they became redundant and have been removed.

Technical comment I wonder if equation (1) is strictly correct because xi represent the 10 input variables and wi the 4 weights, both carrying the same index i. Should there be double summation? Correct also notations/subscripts following the equation.

Reply: The equation in section 2.4 (Applying artificial neural networks to data) has now been corrected and the annotation updated.

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