Estimating Wetland Methane Emissions in Northern High Latitudes Utilizing Artificial Neural Networks from 1990 to 2009

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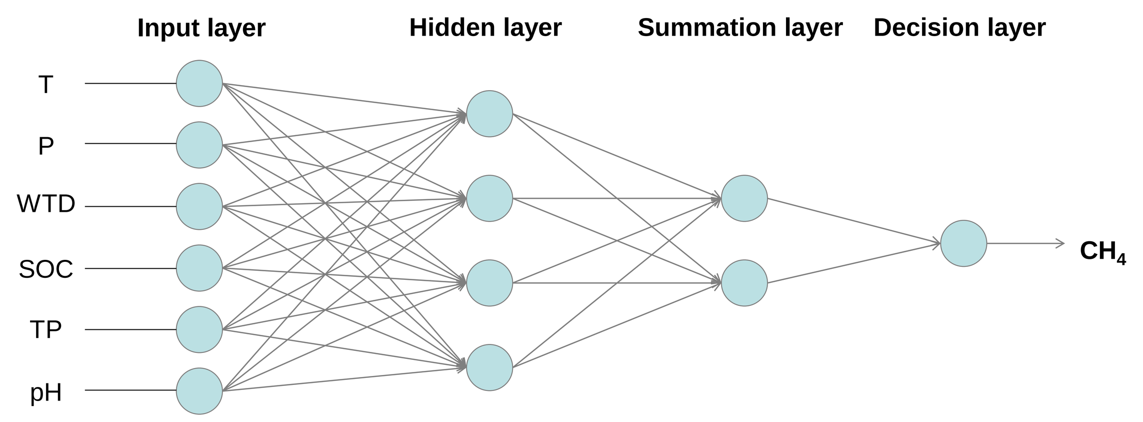
Introduction

Wetlands are thought to be the single largest natural source of atmospheric methane (CH_4). Northern high latitudes (north of 45 °N) contains vast areas of wetlands, and CH_4 emissions from wetland ecosystems in the region provide a potentially positive feedback to global climate warming. Compared to low-latitudes, the region has been experiencing more dramatic environmental changes, including higher temperatures, increases in precipitation, and melting of permafrost. The alterations of soil thermal and hydrological regimes in the region have resulted in changes in the magnitude and timing of CH_4 fluxes. To date, the uncertainty of CH_4 budgets of northern wetlands in the region is still large. Here, we use a data-driving Artificial Neural Networks (ANN) approach to estimate wetland CH_4 emissions in northern high latitudes, based on available site-level measurements of CH_4 fluxes.

Methods

We use an ANN model, Generalized Regression Neural Network (GRNN, Zhuang *et al.*, 2012), to represent non-linear regression between filed measurements of CH_4 fluxes and six explanatory variables: mean air temperature (T), precipitation (P), water table depth (WTD), soil organic carbon (SOC), soil total porosity (TP), and soil pH. Driven with spatially-explicit data of monthly climate, hydrology, and soil properties, the developed ANN model is then extrapolated to northern high latitudes to estimate wetland CH_4 emissions from 1990 to 2009 at a 0.5º resolution.

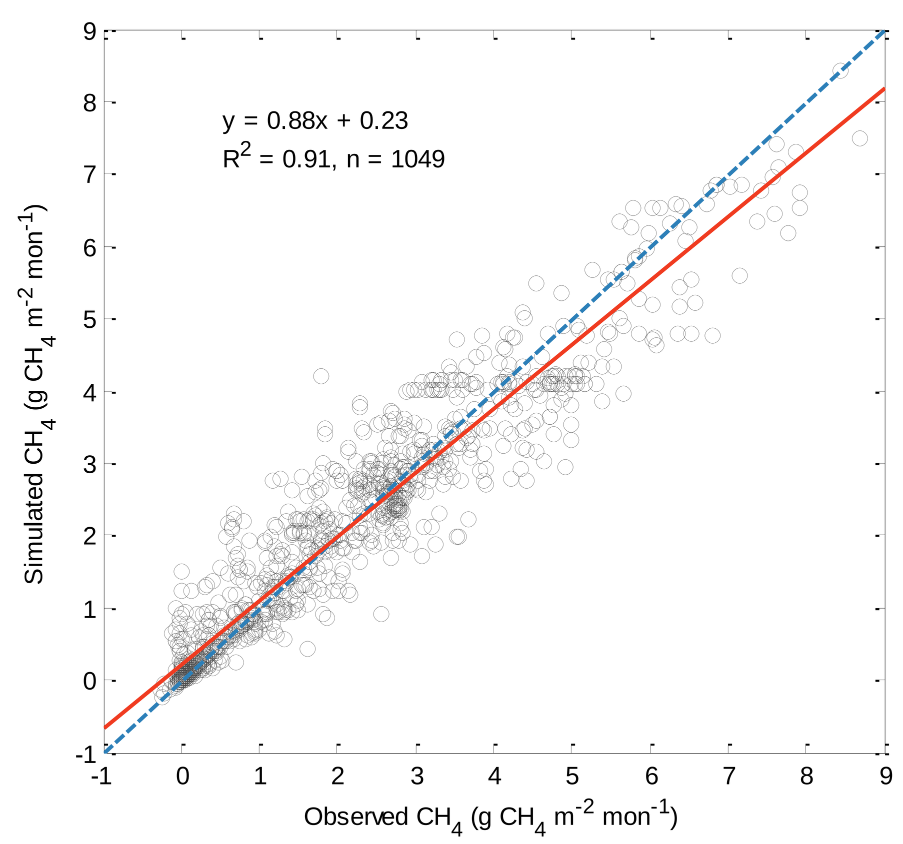
Site-level data collected from peer-reviewed literatures contain 1049 records at 34 sites, covering a range of wetland types under various field conditions. For spatially-explicit data, the monthly climate data are extracted from CRU TS3.1 datasets (Mitchell & Jones, 2005). The soil properties data are taken from ISRIC-WISE spatial soil database (Batjes, 2006). The fraction of wetland extent is determined by the 30-second GLWD-3 dataset (Lehner & Döll, 2004), while the WTD of wetlands is derived from hydrological model simulations (Zhuang *et al.*, 2002; Zhuang *et al.*, 2004) combining with a TOPMODEL-based method (Lu & Zhuang, 2012).



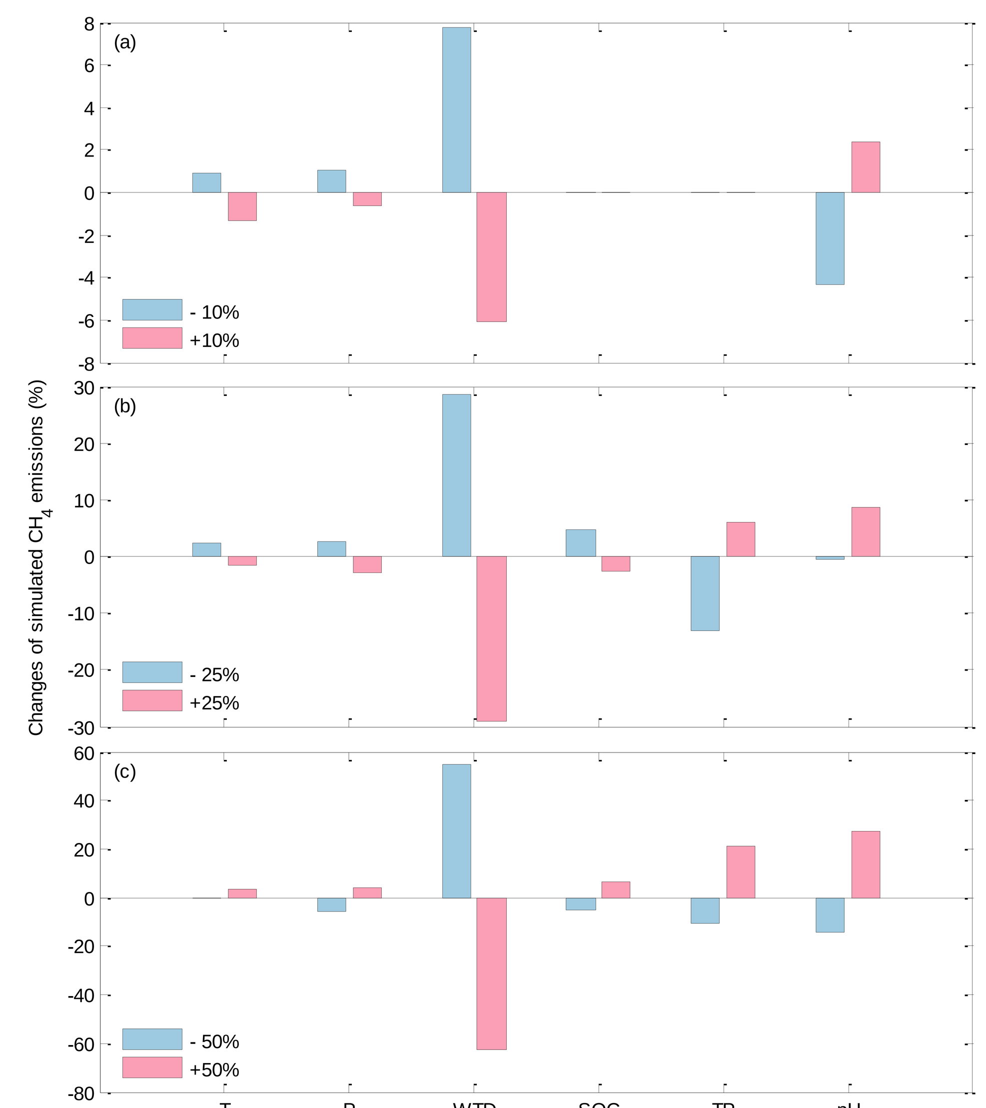
Schematic diagram of the GRNN model for estimating wetland CH_4.

References: Batjes, 2002, Soil Use and Management, 18, 232-235; Lehner and Doll, 2004, doi:10.1016/j.jhydrol.2004.03.028; Lu & Zhuang, 2012, doi:10.1029/2011JG001843; Mitchell & Jones, 2005, International journal of climatology, 25, 693-712; Zhuang *et al.*, 2002, J. Geophys. Res., 107, 8147; Zhuang *et al.*, 2004, Global Biogeochem. Cycles, 18, GB3010; Zhuang *et al.*, 2012, doi: 10.1016/j.atmosenv.2011.11.036

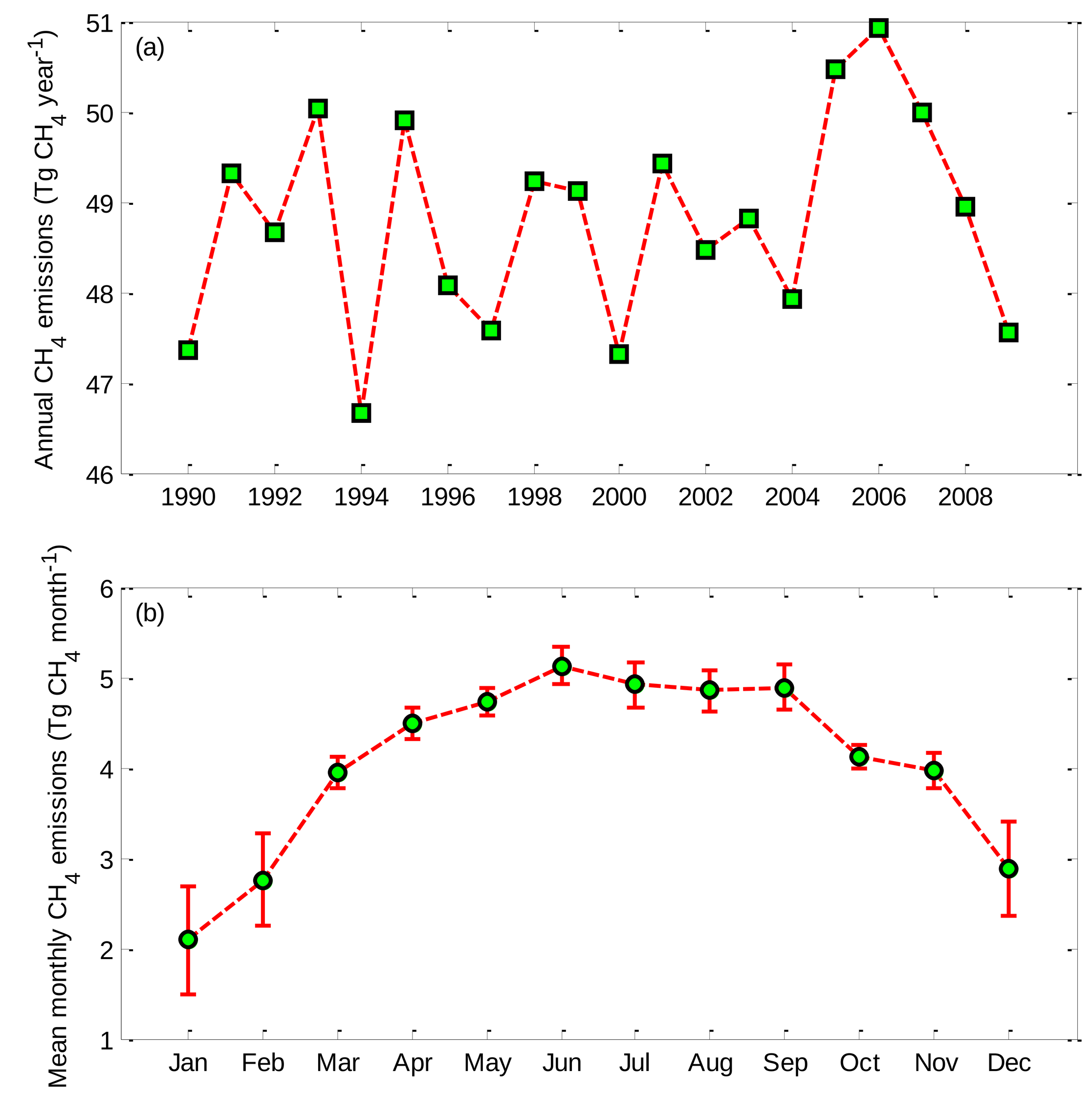
Results



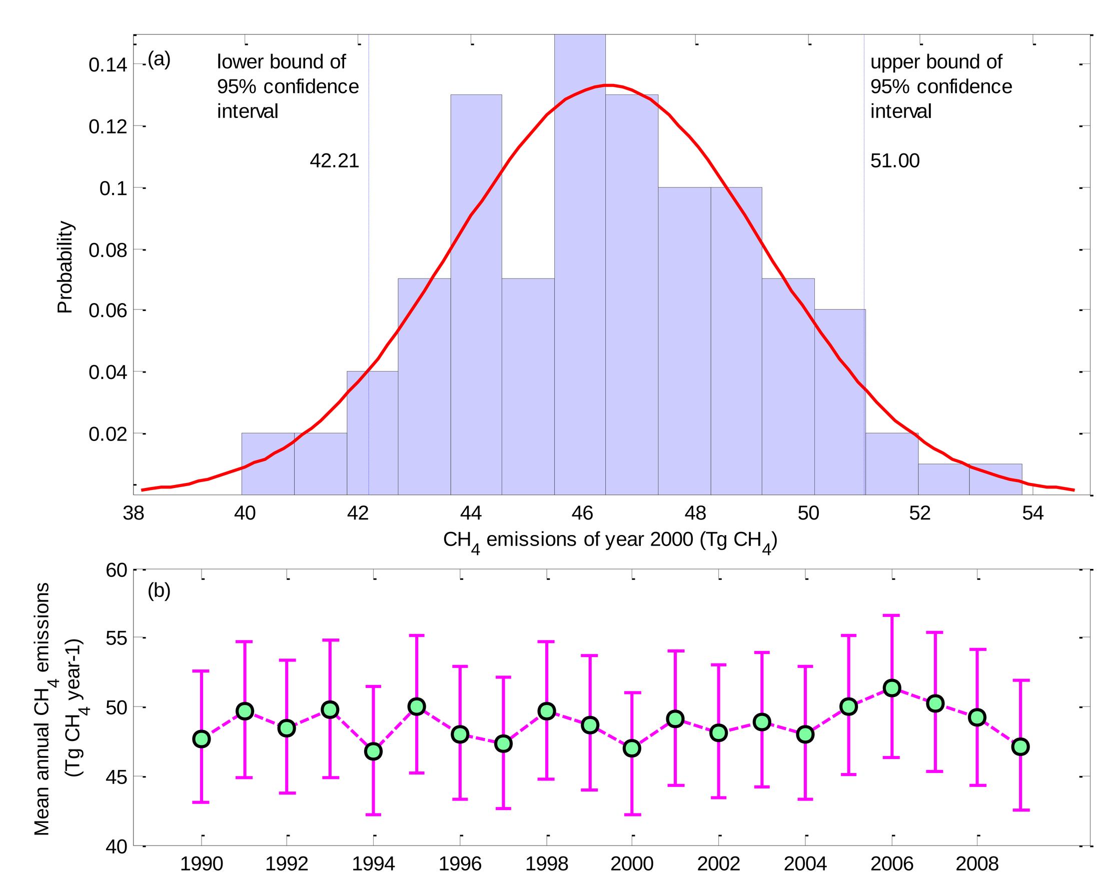
Comparisons between the measured and modeled CH_4 emissions. Dashed line is the 1:1 line.



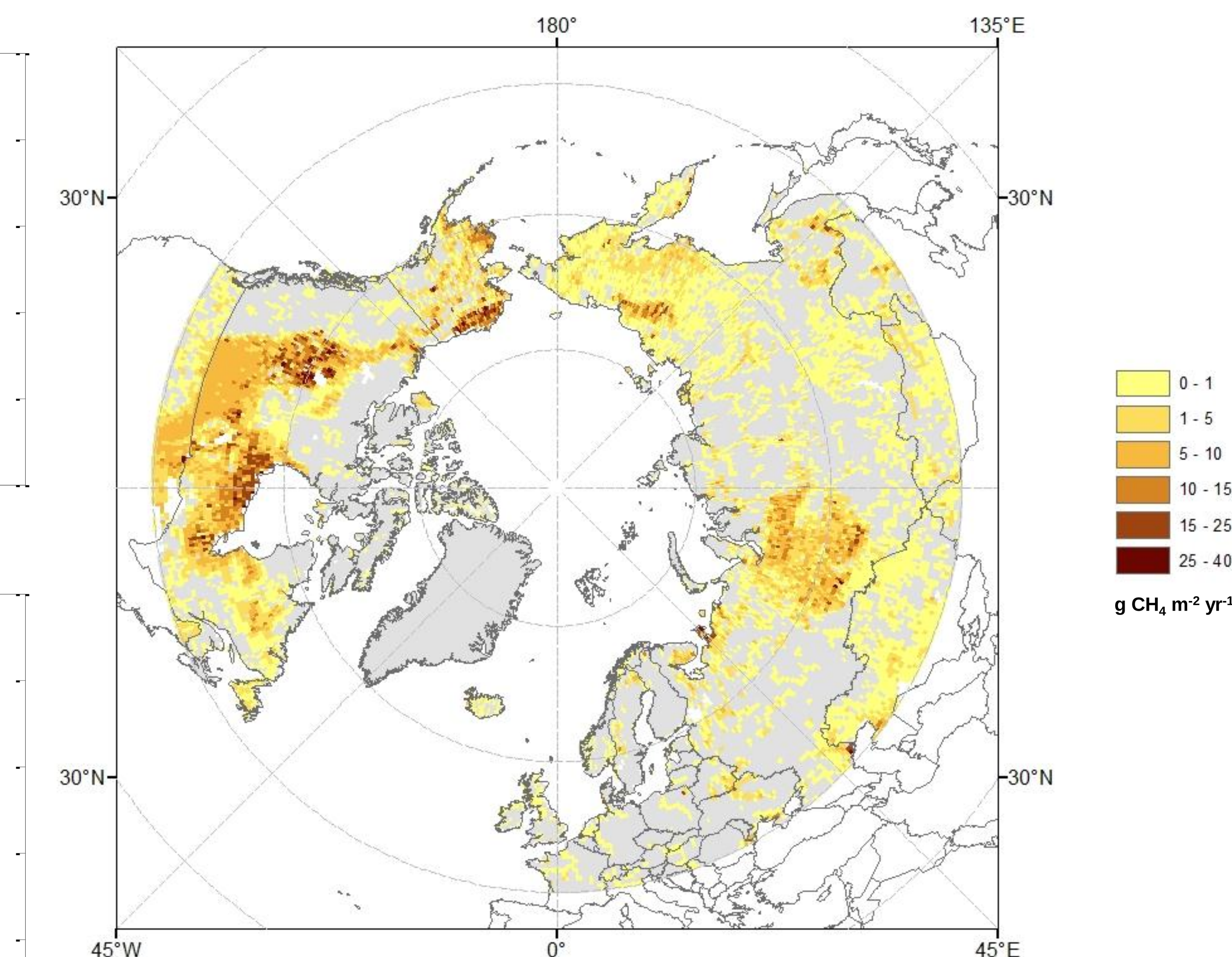
Sensitivity of the ANN model to changes in input variables. The changes are calculated based on the "baseline" simulation using the unchanged regional input data.



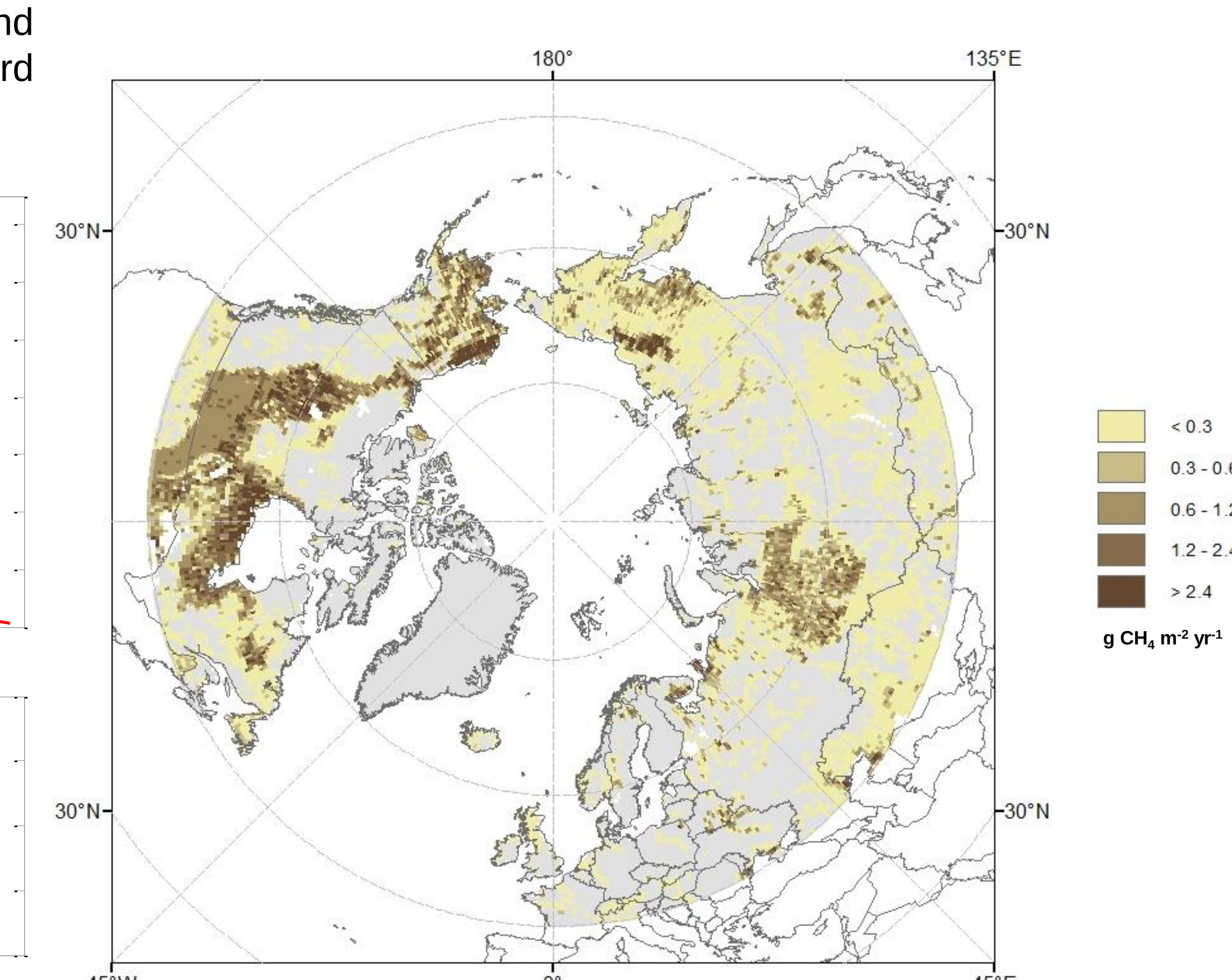
Inter-annual (a) and seasonal (b) variations of wetland CH_4 emissions. The error bars indicate one standard deviation of monthly emissions during 1990-2009.



Uncertainties of the estimated wetland CH_4 emissions based on one hundred ANN models developed from different subsets of original site-level data: (a) probability distribution of annual CH_4 emissions of year 2000, and (b) inter-annual variations of annual CH_4 emissions and the 95% confidence intervals (error bars) from 1990 to 2009.



Spatial patterns of wetland CH_4 emissions, averaged over 1990-2009.



Standard deviation of annual wetland CH_4 emission rates for year 2000, simulated with the one hundred ANN models.

Summary

The developed ANN model fits well with the observed CH_4 fluxes at site level. The mean annual wetland CH_4 emissions in northern high latitudes are estimated to be 48.7 Tg CH_4 yr^{-1} with an uncertainty range of 44.0-53.7 Tg CH_4 yr^{-1}, and there are both significant inter-annual and seasonal variations of emissions during the period of 1990-2009. We find that the regional wetland CH_4 emissions are most sensitive to variations of water table position. The simulated wetland CH_4 emissions show a large spatial variability due to variations in hydrology, climate, and soil conditions. This study highlights the importance of better characterization of the hydrological dynamics of wetlands (i.e., water table position), in quantifying regional CH_4 emissions from northern wetlands.

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