Abstract

This PhD thesis was supported by the EU Marie Curie FP6 Program GREENCYCLES - Biogeochemistry and Climate Change Research and Training Network. The main aim of the research was improvement of dynamic and spatially distributed $\text{CH}_4$ cycle models for Earth System simulation. The emphasis laid on optimal parameterisation of hydrological processes and on the carbon cycle of permafrost ecosystems. The research focused on improvement of the parameterisation of PEATLAND-VU process-based model of $\text{CO}_2$ and $\text{CH}_4$ exchange, and assess the effects of spatial heterogeneity and model resolution.

Nature development and restoration in The Netherlands involves usually the restoration of high water tables in former agricultural areas and extensivation or abandonment of agricultural activities. Wet peat soils are known to emit considerable quantities of $\text{CH}_4$, while drained agricultural soils emit $\text{CO}_2$ from decomposition of the soil organic matter. Therefore, these land use changes may affect the greenhouse gas (GHG) emissions and an assessment of their effects is useful for environmental policy. Based on these facts, the aim of the first study was to assess $\text{CO}_2$ and $\text{CH}_4$ fluxes from wetland nature reserves in the Dutch province of Drenthe, using the PEATLAND-VU model. Since surface flux observations in the province are absent and cannot be obtained in a short (< 1 year) time frame, model validation from elsewhere was extrapolated to the research area. In this way a cost-effective methodology was developed for land use-related greenhouse gas emission assessments, which can be applied by local governments at a sub-national scale.

The PEATLAND-VU model was used to simulate the $\text{CH}_4$ and $\text{CO}_2$ emissions for the years 2005-2007 and for May/June 2008. Previous field validation of the model elsewhere was checked for local validity with $\text{CH}_4$ and $\text{CO}_2$ flux measurements in short field campaigns in May/June 2008, at two locations, Visvliet and Balloërveld. These sites represent respectively eutrophic and oligotrophic peat and peaty soils, and showed large differences in fluxes. These flux differences were simulated correctly by the model by adapting the vegetation net primary production and methane oxidation parameters. Next, model simulations were run for eight combinations of vegetation and soil type. Using the simulated fluxes and the areal extent of the soil-vegetation combinations, a GIS-based up-scaling over all nature reserves was made.

This study showed that river valley floors with mesotrophic and eutrophic peat soils dominate the greenhouse fluxes of the area. $\text{CH}_4$ fluxes are high in wet terrain, while the $\text{CO}_2$ fluxes are high when water table is lower. The fluxes from oligotrophic peat soils are comparatively low. Nature development can contribute to a decrease of the total greenhouse gas flux from peat soils and to conservation of soil organic matter in the soil.

Parameter uncertainty at site level is an important factor in large scale modelling of $\text{CH}_4$ fluxes. $\text{CH}_4$ fluxes are known to be spatially highly variable on a small scale. If a model parameter has a strong influence on the modelled fluxes on a local scale, it is likely that it has also a large influence in an up-scaled version of this model, and in any model that attempts to model fluxes at a larger scale. The objective of the second study was to identify which are the model’s most sensitive parameters and determine their interdependence when moving from regional to global scale modelling and how to fit best these parameters based on observations. With this objective the study tried to quantify parameter uncertainty on behalf of the previous and next studies. It is important to know at which level of detail processes need to be modelled to represent the interactions between soil, climate and management correctly.

Several studies showed that beside the water table position, difference in vegetation and soil properties are also influential to understand interactions of wetland $\text{CH}_4$ emission with climate or
wetland management. Thus, for large scale modelling of these emissions and coupling to climate or hydrological models knowledge of the sensitivity of the related parameters is highly important. Therefore, the PEATLAND-VU model was tested using the GLUE (Generalized Likelyhood Uncertainty Estimation) method. For validation, data from three different sites, including temperate and permafrost wetlands, were used (Kytałyk-NE Siberia, Horstermeer-The Netherlands and Ruwiel-The Netherlands). The parameter sensitivity and the parameter values resulting from the GLUE optimisation agree well with a priori knowledge on the parameters. The results showed that the PEATLAND-VU model is estimating the CH$_4$ fluxes better than an estimate based on averaged data, but does not clearly outcompete a regression model based on local data. It is capable of reproducing larger scale (seasonal) temporal variability in the data, but not the small-scale (daily) temporal variability. It is not strongly sensitive to soil profile parameters, but is sensitive to parameters determining CH$_4$ transport and oxidation in vegetation, and the temperature sensitivity of the microbial population. The main conclusion of this study states that the up-scaling of this plot-based wetland CH$_4$ emission model is feasible but considerable improvements of wetland CH$_4$ modelling will result from an improvement of the parameterisation of the wetland vegetation characteristics.

The magnitude of the CH$_4$ emissions from wetlands is controlled by the dynamic balance between CH$_4$ production and oxidation rates in the peat profile and by transport mechanisms. Measured emissions demonstrate high spatial and temporal variation and are linked to environmental factors such as variation in temperature and ground water level. The third study’s purpose was to quantify/study the effect of water table, temperature and different vegetation types, at two high latitude wetland sites on CH$_4$ emission, by means of field measurements and modelling, with data from the years 2004 to 2006. The PEATLAND-VU model was used to simulate the emissions. The first site, Kytałyk, is located in Northeast Siberia, in a continuous permafrost region with a mean annual temperature of $-14.3$ °C, the other site is the Stordalen mire ten kilometres east of Abisko, northern Sweden. It is located in a discontinuous permafrost region with sub arctic climate with a mean annual temperature of $-0.7$ °C. Model input consisted of observed temperature, precipitation and snow cover data.

The modelled CH$_4$ emissions showed direct correlation between variations in water table and soil temperature variations. The differences in CH$_4$ emissions between the two sites were caused by different climate, hydrology, soil physical properties, vegetation type and net primary production (NPP). For Kytałyk the simulated CH$_4$ fluxes showed similar values as the observations during the growing season while for Stordalen the simulated fluxes showed a slightly lower average value than the observed ones. The effect of the longer growing season at Stordalen was simulated correctly. This study showed that modelling of arctic CH$_4$ fluxes was improved by adding a relatively simple hydrological model that simulates the water table position from generic weather data. The results support the generalisation in literature that CH$_4$ fluxes in northern wetland are regulated more tightly by water table than temperature.

CH$_4$ emissions from boreal and arctic wetlands potentially constitute a positive feedback to global climate warming. Many process-based models have been developed but high uncertainties in estimating the amount of CH$_4$ released from wetlands at the global scale still exist. The aim of the last study was to improve global estimates of CH$_4$ emissions by up-scaling a wetland CH$_4$ emission model, PEATLAND-VU, to the global scale over the period 2001-2006 at a spatial resolution of 0.5°. For that purpose, PEATLAND-VU was coupled to a global hydrological model, PCR-GLOBWB. This coupling was based on the global circum-arctic distribution of wetlands with hydrological conditions being specified by the global hydrological model, PCR-GLOBWB, comprising water table depths and snow thickness, the parameterisation included air temperature
as obtained from the ECMWF operational archive forecast. To establish the influence of uncertainty in the representations of the circum-arctic distribution of wetlands on the results, different existing products were used to aggregate the emissions. Using the delineation of potential peatlands from the FAO/ISRIC digital soil map of the world and the representation of floodplains in PCR-GLOBWB itself, the average annual flux over the period 2001-2006 was estimated to be 78 Tg yr\(^{-1}\). In comparison, the six year average CH\(_4\) fluxes were 37.7 Tg yr\(^{-1}\) using the Matthews and Fung (1987) dataset, 89.4 Tg yr\(^{-1}\) using Prigent et al. (2007), 145.6 Tg yr\(^{-1}\) using Lehner and Döll (2004), and 157.3 Tg yr\(^{-1}\) following Kaplan (2002) approach. This study shows the feasibility of high resolution modeling of CH\(_4\) emissions using coupled hydrological and CH\(_4\) emission process models to model interannual variability in CH\(_4\) emissions, and highlights the importance of an adequate understanding of hydrology in quantifying the total emissions from northern hemispheric wetlands. Knowledge of the sub-grid variability in wetland extent helps to prescribe pertinent hydrological conditions to the emission model as well as to identify the uncertainty associated with existing wetland distributions.