Supplementary section

CLM-Microbe: This model simulates CH_4 fluxes from different wetland and peatland types by explicitly simulating microbial processes of CH_4 production (hydrogenotrophic methanogenesis based on H_2 and CO_2 and acetoclastic methanogenesis based on acetic acid) and CH_4 oxidation (aerobic and anaerobic methanotrophy) and dissolved organic carbon fermentation (Xu et al., 2015; Wang et al., 2019). Overall, this model simulates interactions between substrate production, environmental factors, peat carbon mineralization, CH_4 production, oxidation and CH_4 transport pathways (plant transport, ebullition, and diffusion) (Xu et al. 2015; Wang et al., 2019). Hydrological processes such as interception, throughfall, canopy drip, snow melt and accumulation, infiltration, evaporation, surface runoff, sub-surface drainage, groundwater discharge and recharge in soil and unconfined aquifer (Oleson et al., 2010) are simulated using Community Land Model (CLM4.5) (Thornton et al., 2007; Koven et al., 2013). The model simulates ten soil/peat layers, five snowpack layers overlying the soil layers and five bedrock layers underneath the soil layers (Xu et al., 2015; Wang et al., 2019; Zuo et al., 2022).

HIMMELI: Helenski Model of Methane Build-up and Emission for Peatlands (HIMMELI) is not a full carbon peatland model, but rather an independent CH_4 module simulating production, oxidation and three transport pathways (plant transport, ebullition, and diffusion) from wetlands and peatlands (Raivonen et al., 2017). This model simulates a 1-dimensional vertical layered peat profile driven by peat temperature, leaf area index (LAI), water table depths (WTDs) and anaerobic carbon decomposition rate where the model user can define the peat depths and layer thickness (Raivonen et al., 2017). The WTDs divide the 1-D vertical peat column into water filled and air-filled parts, greatly impacting CO_2, O_2 and CH_4 fluxes. The vertical root distribution determines the anoxic respiration and gas transport into roots (Raivonen et al., 2017). If the model user defines a peat depth of more than 2 m, then the model does not simulate root growth beyond 2 m depth (Raivonen et al., 2017).

Peatland-VU: Peatland-VU is a process-based model that simulates CO_2 and CH_4 fluxes from peat soils based on 4 sub-modules: soil physics module for computing peat temperature, water saturation, WTDs, ice content; CO_2 and CH_4 sub modules and organic production sub module (van Huissteden et al., 2006; 2009). The multiple soil organic matter (SOM) pools in the model such as peat, solid and liquid manure, litter, roots, rhizodeposition, microbial biomass and resistant soil organic matter are adapted from Jenkinson and Rayner (1977). Each SOM pool has a specific decomposition rate, impacted by peat temperature, peat moisture, pH and priming (van Huissteden et al., 2006). The decomposition reaction for each SOM pool is partitioned between CO_2, microbial biomass and humus pool based on first order rate kinetics (Jenkinson and Rayner 1977; van Huissteden et al., 2006; 2009). The peat temperature is computed using heat flow equation, a function of time, peat depth and thermal diffusivity, varying strongly with water contents (van Huissteden et al., 2006).

BASGRA-BGC: Basic Grass Model-Biogeochemical Cycle is a process-based model simulating C balance, biomass productivity and CO_2 and CH_4 fluxes from drained peatlands cultivated with grasslands (Huang et al., 2021). BASGRA-BGC is a process based daily time step derived from BASGRA simulating grass roots dynamics, biomass productivity and tillers with detailed processes for cold hardening and dehardening (Höglind et al., 2016). The BASGRA-N module incorporates soil physical, biological, and detailed soil N processes and plant N allocations (Höglind et al., 2016; 2020). However, BASGRA-N simulates single soil/peat layer, does not simulate drainage and CH_4 process (Höglind et al., 2016; 2020) and therefore, BASGRA-BCG simulates multiple vertical soil/peat layers having detailed hydrological and biogeochemical processes, while simultaneously simulating CO_2 and CH_4 fluxes from drained grassland peat soils (Huang et al., 2021). The different simulated hydrological processes are soil water infiltration, evaporation and transpiration, soil temperature, and freezing and thawing processes (Arnold and Fohrer, 2005). The decomposition of litter and soil organic matter is derived from Century model and partitioned into two litter pools (structural and metabolic) and three soil organic matter pools (labile, passive, and slow) (Parton, 1996). This model accounts for oxygen stress to the grass, based on a simple linear curve derived from Aquacrop model (Raes et al., 2012) since peat soils often exhibit waterlogged conditions leading to oxygen stress for grass growth (Huang et al., 2021).

Wetland DNDC: Wetland-DNDC is a process-based model simulating interactions between climate, soil physical processes, plant growth, soil and plant decomposition, soil nitrification, denitrification, and fermentation (Li et al., 1992, 2000; Stange et al., 2000; Zhang et al., 2002a, b). The soil, plant and decomposition sub-models quantify soil temperature, soil moisture, pH, redox, while nitrification, denitrification and fermentation sub models simulate biogeochemical processes regulated by microbial reactions, plant roots, litter, and hydrology (Deng et al., 2015). The plant litter production and its incorporation into soil organic matter is based on C:N ratio, decomposition rates, peat temperature and moisture conditions (Li et al.,1992). The CH_4 production is simulated using electron donors (H_2 and dissolved organic carbon (DOC)) and acceptors (NO_3, Mn^{4+}, Fe^{3+}, SO_4^{2-}, and CO_2) respectively (Deng et al.,2015). The Wetland DNDC was modified by Li et al. (2004a) to simulate variable water levels, harvesting of forest, tree planting, chopping, and burning.

ORCHIDEE-PCH$_4$: The Organizing Carbon and Hydrology in Dynamic Ecosystems (ORCHIDEE) is a dynamic global land surface model simulating carbon, water and energy fluxes between biosphere, land surface, geosphere, and atmosphere (Qiu et al., 2018). The carbon in ORCHIDEE simulates photosynthesis, respiration, soil carbon cycle, CO_2 production and GHG emissions (Qiu et al., 2018). Since the ORCHIDEE model did not simulate soil thermal processes, hydraulic processes, snowpack dynamics and plant and soil carbon fluxes, the ORCHIDEE-MICT (Guimberteau et al., 2018) and ORCHIDEE-Peat (Largeron et al., 2018; Qiu et al., 2018; Qiu et al., 2019) were developed. The ORCHIDEE-Peat does not simulate three carbon pools (active, passive, and slow) as simulated by ORCHIDEE and ORCHIDEE-MICT, but rather simulates two distinct pools (acrotelm and catotelm) (Qiu et al., 2018). So, the carbon from the decomposed litter pool is added into the acrotelm and catotelm pool which is located above and below the water table respectively (Qiu et al., 2018). The carbon in acrotelm in decomposed aerobically and anaerobically if above and below water table respectively, while the permanently saturated catotelm receives a prescribed fraction of carbon from the acrotelm pool which is decomposed anaerobically at a very slow rate (Qiu et al., 2018). The hydrological processes simulated by the model are rainfall interception, soil water transport, latent and sensible heat fluxes, and heat diffusion in soil/peat (Largeron et al., 2018; Qiu et al., 2018). The CH_4 production, oxidation and transport derived from Khvorostyanov et al. (2008a, b) and incorporated into ORCHIDEE-Peat (Qiu et al., 2018) and ORCHIDEE-PCH$_4$ (Salmon et al., 2022). ORCHIDEE-PCH$_4$ simulates different plant functional types (PFTs) such as mosses, sedges, graminoids and grasslands (Qiu et al., 2018; Salmon et al., 2022).

WETMETH 1.0: WETMETH is a process-based model integrated into University of Victoria Earth System model (UVic ESCM) (Weaver et al., 2001) for simulating CH_4 fluxes from wetlands and peatlands (Nzotungicimpaye et al., 2021). The UVicESCM is a three-dimensional ocean circulation model inbuilt into thermodynamic sea-ice model and two-dimensional energy moisture balance model for simulating interactions between the atmosphere and land surface (Weaver et al., 2001). The land surface component of this model is derived from Met Office Surface Exchange Scheme (MOSES) having 14 layers of unequal thickness up to a depth of 250 m and simulates freeze-thaw dynamics (Avis et al., 2011). The top 8 layers are soil layers having a total depth of 10 m, that interact with atmosphere and simulate water cycle, while the remaining 6 layers are bedrock layers (Avis et al., 2011). WETMETH 1.0 embedded into UVicESCM, operates at 3.6° longitude and 1.8° latitude (Weaver et al., 2001). However, the wetlands and peatlands are identified within each grid cells based on topography (TOPMODEL) and moisture contents (Gedney and Cox, 2003; Avis et al., 2011) and simulates 5 plant functional types: broadleaf trees, needleleaf trees, shrubs, C3 and C4 grasses (Cox, 2001; Matthews et al., 2004; Meissner et al., 2003) derived from dynamic global model known as TRIFFID (Top-down Representative of Interactive Foliage and Flora including Dynamics) (Nzotungicimpaye et al., 2021).

Terrestrial Ecosystem Model (TEM): TEM is a process based biogeochemical model simulating interactions between carbon, nitrogen, water, heat, and soil for terrestrial ecosystems (Melillo et al., 1993; Zhuang et al., 2007). TEM-CH$_4$ module simulates CH_4 production, oxidation and transport between peat and atmosphere. The CH_4 production in anaerobic zone is regulated by soil/peat thermal conditions, pH, redox, and organic substrate (Zhuang et al., 2004; Tang et al., 2010), while CH_4 oxidation in aerobic zone is regulated by soil methane, O_2 concentrations, soil temperature, pH and redox (Zhuang et al., 2004; Tang et al., 2010). The depth of anaerobic and aerobic zones is regulated by WTDs. However, since the model does not simulate O_2 in the aqueous phase, Tang et al. (2010) modified the TEM-CH$_4$ by simultaneously simulating four substances consisting of O_2, N_2, CO_2 and CH_4 with the ebullition simulated using the probabilistic pressure-based algorithm having bubble formation and redissolution (Tang et al., 2010).

TRIPLEX-GHG: It is a process-based model that integrates hydrology, vegetation dynamics (canopy physiology and phenology), terrestrial carbon balance and CO_2 and CH_4 fluxes (Foley et al., 1996; Peng et al., 2013). The WTDs in hydrology module are simulated using volume of water in the peat profile, porosity, minimum volumetric water content and evaporation (Frolking and Crill, 1994; Granberg et al., 1999; Zhuang et al., 2004). However, the model does not simulate drainage from the bottommost peat layer, while the excess water is released as runoff when the position of the water table is higher than the maximum standing water (Zhu et al., 2014). The model simulates 6 soil/peat layers having a total depth of 4 m.

Lund-Potsdam-Jena Wetland Hydrology and Methane DGV Model (LPJWhyMe v1.3.1): LPJWhyMe was added to the original model LPJ (Lund-Potsdam-Jena Dynamic Global Vegetation Model) developed by Sitch et al. (2003) and Gerten et al. (2004) and LPJ-Why (Lund-Potsdam Jena Dynamic Global Vegetation Model Wetland Hydrology) developed by Wania et al. (2009a, b). LPJ is a process-based model simulating interactions between plant physiology, carbon allocation, decomposition, and hydrology. The model simulates different plant functional types (PFTs), with each PFTs having specific physiological parameters, rooting depths, above and below ground biomass, while competing for light and nutrients (Sitch et al., 2003). However, existing PFTs did not simulate permafrost and peatland processes, so two additional PFTs i.e., flood tolerant C3 graminoid and

Sphagnum mosses were developed into LPJWhy. Further, a CH_4 sub-routine was added into LPJWhy, having a potential carbon pool for methanogensis known as LPJWhyMe. This pool was distributed in all soil layers, dependent upon root distribution in each soil layer having greater carbon allocation in the uppermost layers having greater root densities, compared to deeper soil layers with lower root densities (Wania et al., 2010). The LPJWhyMe simulates decomposition of above and below-ground litter based on fast and slow soil carbon pools having K_{fast} and K_{slow} rates respectively, with these rates being a function of temperature and moisture contents (Wania et al., 2009b; 2010).

Ecosys: This is 3-dimensional mechanistic model simulating interactions between hydrology, soil nutrient transformations and soil thermodynamics using grid cells, discretized soil, and canopy layers (Grant, 1997; 1998; 1999; Grant and Roulet, 2002). This model simulates surface hydrology, subsurface hydrology, infiltration, evaporation and macropore flow (Grant and Roulet, 2002; Morin et al., 2022). The vegetation is simulated using different plant functional types (PFTs) such as annual or perennial, evergreen, or deciduous, vascular, or non-vascular, N_2 fixing and non N_2 fixing and photosynthetic pathway (C3 and C4) (Grant et al., 2017a, b). Importantly, the model simulates different microbial function types (MFTs) based on stoichiometric and bioenergetic constraints. More details on CH_4 production, oxidation and transport pathways found in Grant and Roulet (2002).

CLM4Me: This is a process based CH_4 module developed by Riley et al. (2011) that simulates interactions between climate, soils, plants and hydrology. The CLM4Me is integrated into the CLM4 land model (Lawrence et al., 2011; Oleson et al., 2010). In CLM4Me, the hydrological processes are implemented in each grid cell which are inundated and non-inundated. Currently, the inundated fraction is computed from the simulated WTDs and surface runoff, which is required for computing CH_4 oxidation and production processes (Riley et al., 2011). The CLM4 land model simulates 15 soil layers, with hydrological simulations occurring in top 10 soil layers, while the remaining 5 layers are bedrock (Riley et al., 2011).

PEPRMT: Peatland Ecosystem Photosynthesis, Respiration and Methane Transport (PEPRMT) is a process-based model that simulates CO_2 and CH_4 dynamics in restored freshwater wetlands and rice paddies (Oikawa et al., 2017). PEPRMT simulates three carbon pools, namely fixed labile, stored in plant biomass and older recalcitrant soil organic carbon (Oikawa et al., 2017). The model simulates ecosystem respiration as a combination of autotrophic and heterotrophic respiration and is a function of soil temperature, available substrate, and water table height below the peat surface (Oikawa et al., 2017). The carbon stored in the plant biomass is not available for respiration or methane production, but the carbon stored in the labile and recalcitrant pool is available for respiration and methanogenesis. The CH_4 production is function of available soil carbon in labile pool and soil organic matter pool, maximum rate of methanogenesis enzyme kinetics for respective carbon pools in case of unlimiting substrate concentrations and methanogenesis half saturation concentrations for respective substrates Oikawa et al. (2017). However, the CH_4 production is inhibited by the presence of oxygen and depth of water table below the peat surface. Detailed mathematical equations on production, oxidation and transport provided in Oikawa et al. (2017).

Methane emission model: This is a one-dimensional model where CH_4 dynamics is regulated by the position of the water table from the peat surface and acrotelm and catotelm depths (Lai, 2009). The CH_4 fluxes are computed on a unit basis assuming homogeneous vegetation and microtopography (Lai, 2009). Meanwhile the changes in the water volume are determined using simple water balance. The snowmelt is computed using air temperature, while the potential evapotranspiration is computed based on day length, daily and monthly air temperatures (Lai, 2009). The organic matter decomposition of the acrotelm layer is regulated by the carbon amount, mineralization rate and its thickness, while the organic matter decomposition of the catotelm layer is based on the catotelm specific values (Lai, 2009). Since the anaerobic decomposition of organic matter produces both CH_4 and CO_2, the CH_4 production is adjusted using CO_2:CH_4 production ratio and WTDs. The model does not produce CH_4 below 100 cm due to low availability of labile substrates for methanogenesis (Lai, 2009).

ELM Spruce: ELM Spruce was developed to simulate hydrology, biogeochemistry, vegetation, CO_2 and CH_4 fluxes from forested peatlands (Hanson et al., 2016, 2017, 2020). This model mimics hummock and hollow microtopography's and stimulates lateral and vertical movement of water and solutes (Shi et al., 2015). The CH_4 processes include DOC fermentation, hydrogenotrophic methanogenesis, acetoclastic methanogenesis, aerobic methanotrophy, anaerobic methanotrophy and H_2 production (Ricciuto et al., 2021; Yuan et al., 2021). The model simulates 10 soil layers, with each soil layer having 11 pools and 34 transitions between different pools and detailed carbon and nitrogen cycling processes (Ricciuto et al., 2021; Yuan et al., 2021). The model also tracks concentrations of dissolved organic matter (DOC) and acetate in each soil layer and simulates three CH_4 transport pathways (plant transport, ebullition, and diffusion) (Ricciuto et al., 2021).

CH4MOD: This model was developed to simulate CH_4 fluxes from rice paddies (Huang et al., 1998a ; 2004; 2006), but Li et al. (2010) modified the model to enable it to simulate CH_4 fluxes from natural wetlands. Methane production rates are simulated based on the available methanogenic substrates (root exudates, litter and soil organic matter decomposition), soil temperature, texture and redox potential (Li et al., 2010). The above-ground biomass is simulated based on the growing degree days (GDD), senescence degree days (SDD) and daily mean air temperatures. The model simulates production of carbohydrates from anaerobic decomposition of above-ground and below-ground litter and aerobic decomposition of above-ground litter (Li et al., 2010). The model currently does not simulate water table depths and only simulates two CH_4 transport pathways of plant transport and ebullition (Li et al., 2010).

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