Integrating methane flux dynamics into a terrestrial ecosystem model developed for the high latitudes

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Context

Increased wetland extent globally and precipitation across all seasons in Alaska is projected under climate warming scenarios. Ice-rich discontinuous permafrost lowlands are vulnerable to abrupt thaw, with increases in thermokarst wetland area already observed in interior Alaska. The resulting anoxic environments slow heterotrophic carbon release but increase methanogenesis. This affects the permafrost carbon-climate feedback mechanism though the strength and timing of this effect is highly uncertain Schuur et al. (2015). Process-based terrestrial biosphere models are capable of projecting these dynamics over decadal and centennial scales under various Representative Climate Pathway (RCP) scenarios. Yet, long-term, year round observations of carbon fluxes and drivers (temperature/ moisture) are required to validate model processes. Here we report on our process of integration of methane flux dynamics into a terrestrial biosphere model developed for the high latitudes and discuss parameterization, calibration, and benchmarking of the model leveraging data available through Bonanza Creek LTER.

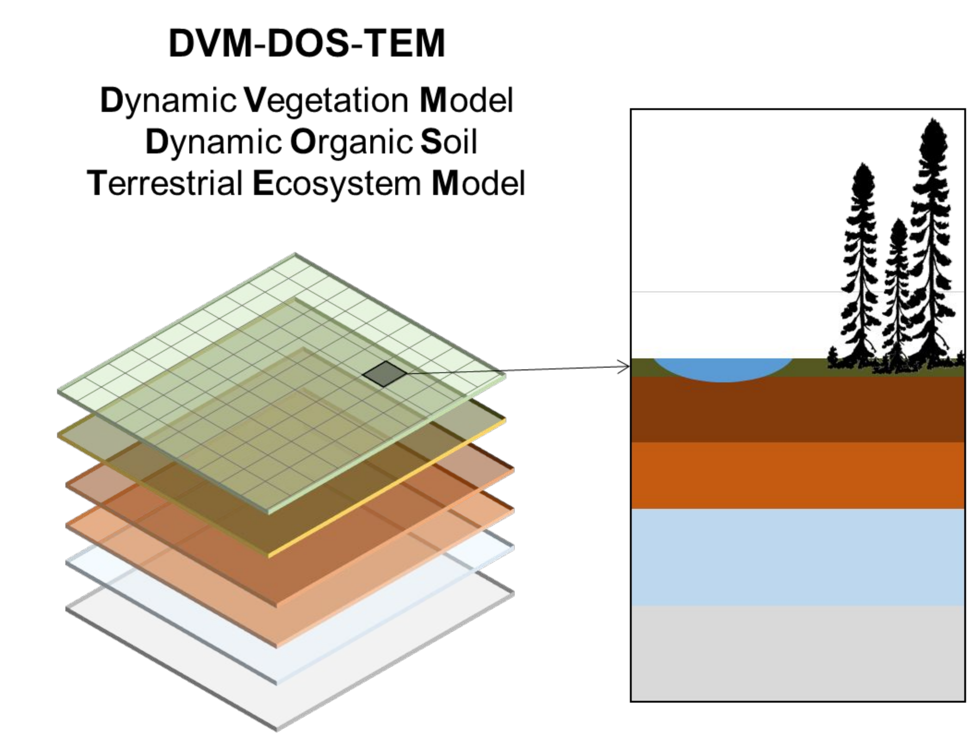

***Figure 1** - Schematic diagram of DVM-DOS-TEM lateral grid cell and vertical soil column structure.*

Model Description

- DVM-DOS-TEM is a process-based Terrestrial Ecosystem Model (TEM) coupling a dynamic organic soil (DOS) module with a dynamic vegetation model (DVM).
- Climatic Research Unit (CRU TS 4.0) climate input forcing data was used to drive the model.
- Community types (CMTs) - grouped soil and vegetation-related parameters characteristic of that community were determined from observational data, literature review, or model calibration.

https://github.com/uaf-arctic-eco-modeling/dvm-dos-tem

Methane Module Calculations

Implemented methane dynamics build on work by Zhuang et al. (2004) and Fan et al. (2013) including methanogenic production, methanotrophic oxidation processes, and diffusion, ebullition, and plant-mediated transport pathways as shown in figure 2.

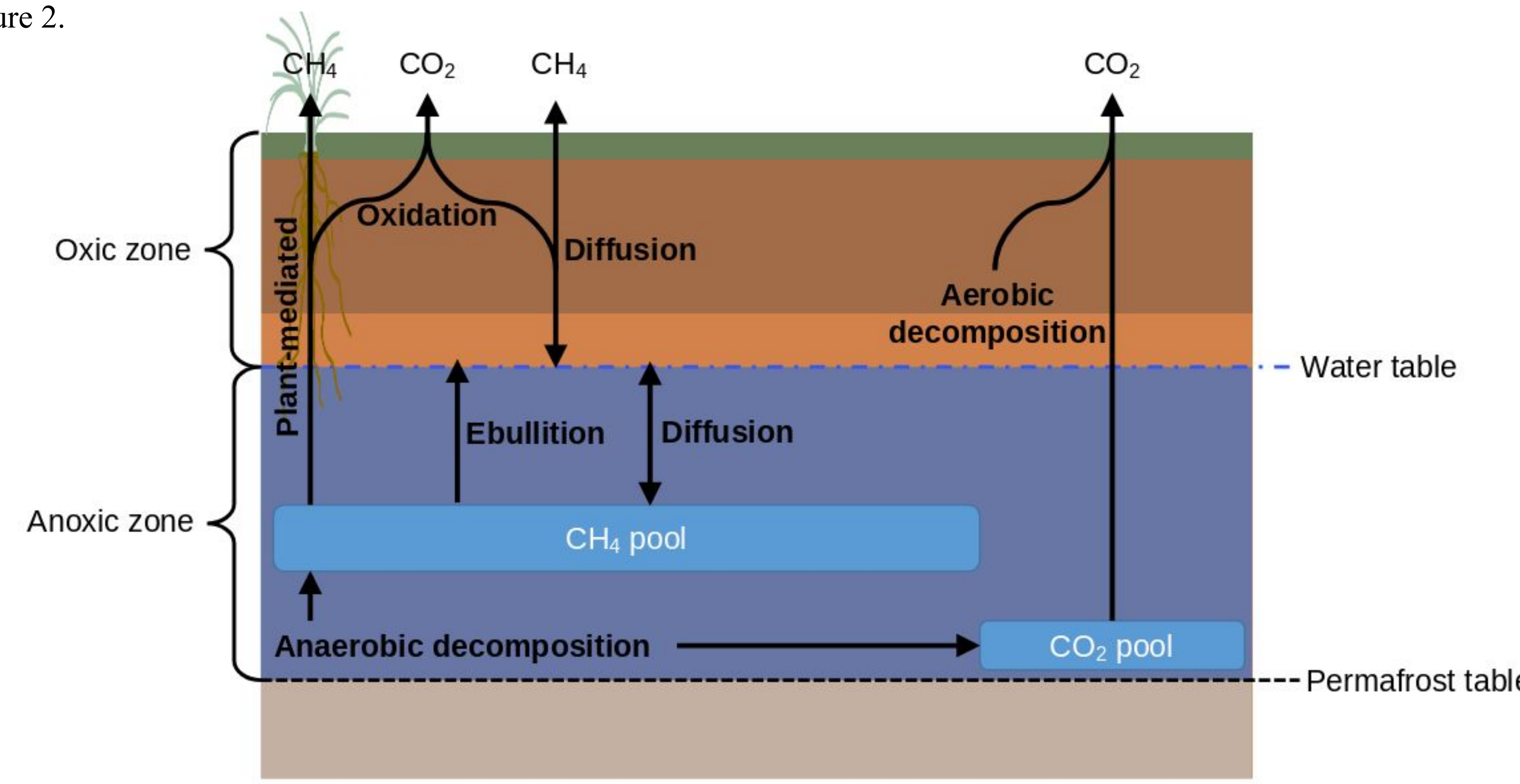

***Figure 2** - Methane production and oxidation processes and transport pathways box and arrow diagram within a conceptual soil column diagram.*

1. The vertical soil column in a grid cell is divided into anoxic and oxic zones based on whether the layer is below or above the water table respectively.
2. Methanogenic production occurs in soil layers below, while methanotrophic oxidation occurs above modulating CH_4 and CO_2 pools.
3. CH_4 is then exchanged between layers by solving equation: $$\frac{\partial C_{CH_4}}{\partial t} = Prod - \frac{\partial diff}{dz} - Ebul - Oxid - Plant$$
4. Transport pathways are constrained as follows:
   a. Ebullition can only occur in saturated layers (below the water table)
   b. Plant-mediation transports a fraction of CH_4 from within the rooting zone, assuming 50% rhizospheric oxidation
   c. Diffusion happens within oxic and anoxic zones, with magnitude dependent on diffusion coefficient and soil tortuosity
5. Surface CH_4 efflux is calculated from summing diffusion occurring between the surface soil layer and the atmosphere (upper boundary condition) plant-mediated transport and if the water table is above or at the soil surface ebullition.
6. Oxidized CH_4 is converted to CO_2 and included into the total soil respiration (as shown in figure 3).

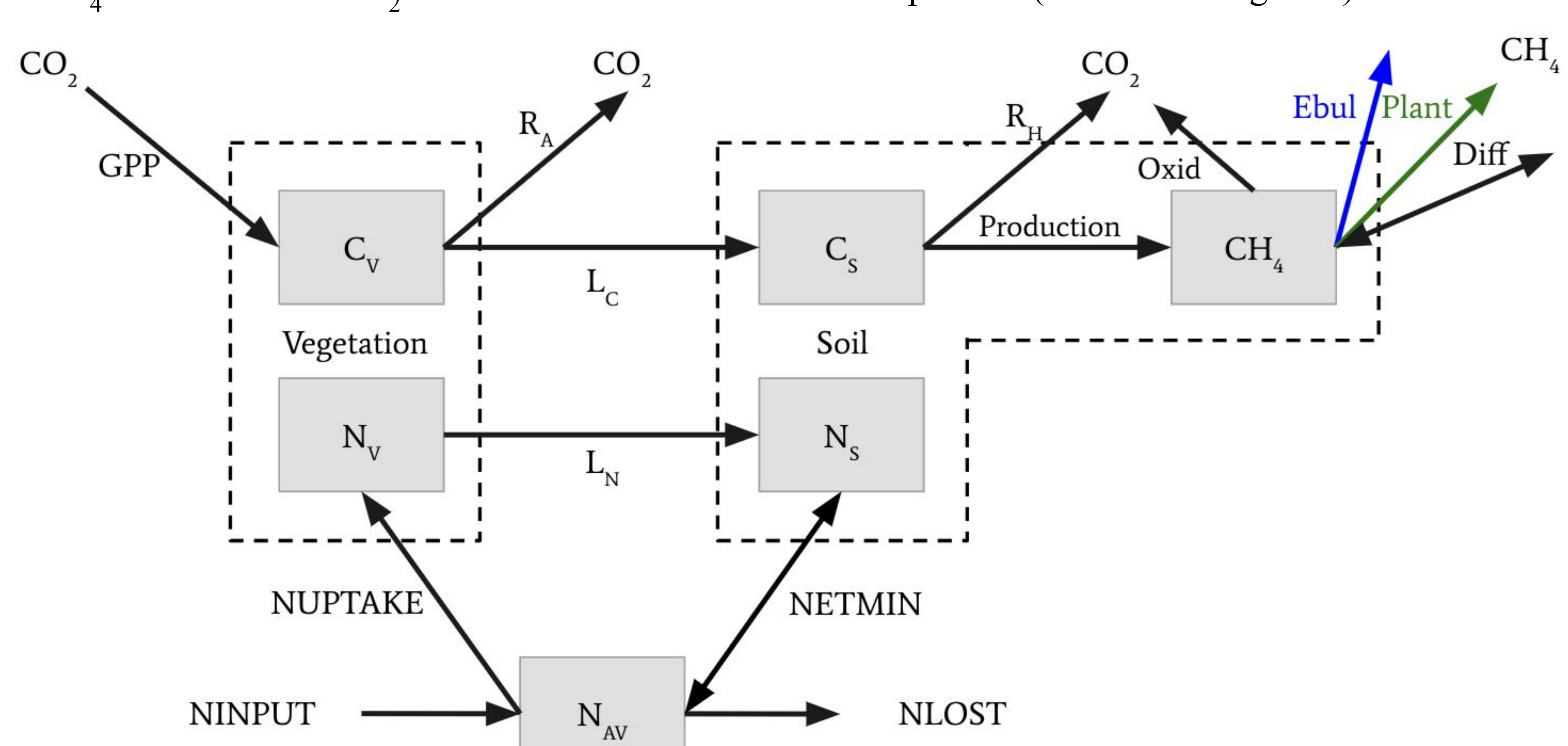

***Figure 3** - Methane flux dynamics coupled into DVM-DOS-TEM existing carbon balance framework.*

Results

To parameterize, calibrate, and benchmark the model comparison has been made between adjacent sites at the Alaskan Peatland Experiment (APEX) as shown in figure 4. This includes a stable but vulnerable permafrost peat plateau (US-BZS) and degrading thermokarst bog (US-BZB) with continuous flux tower monitoring (Euskirchen E. S.).

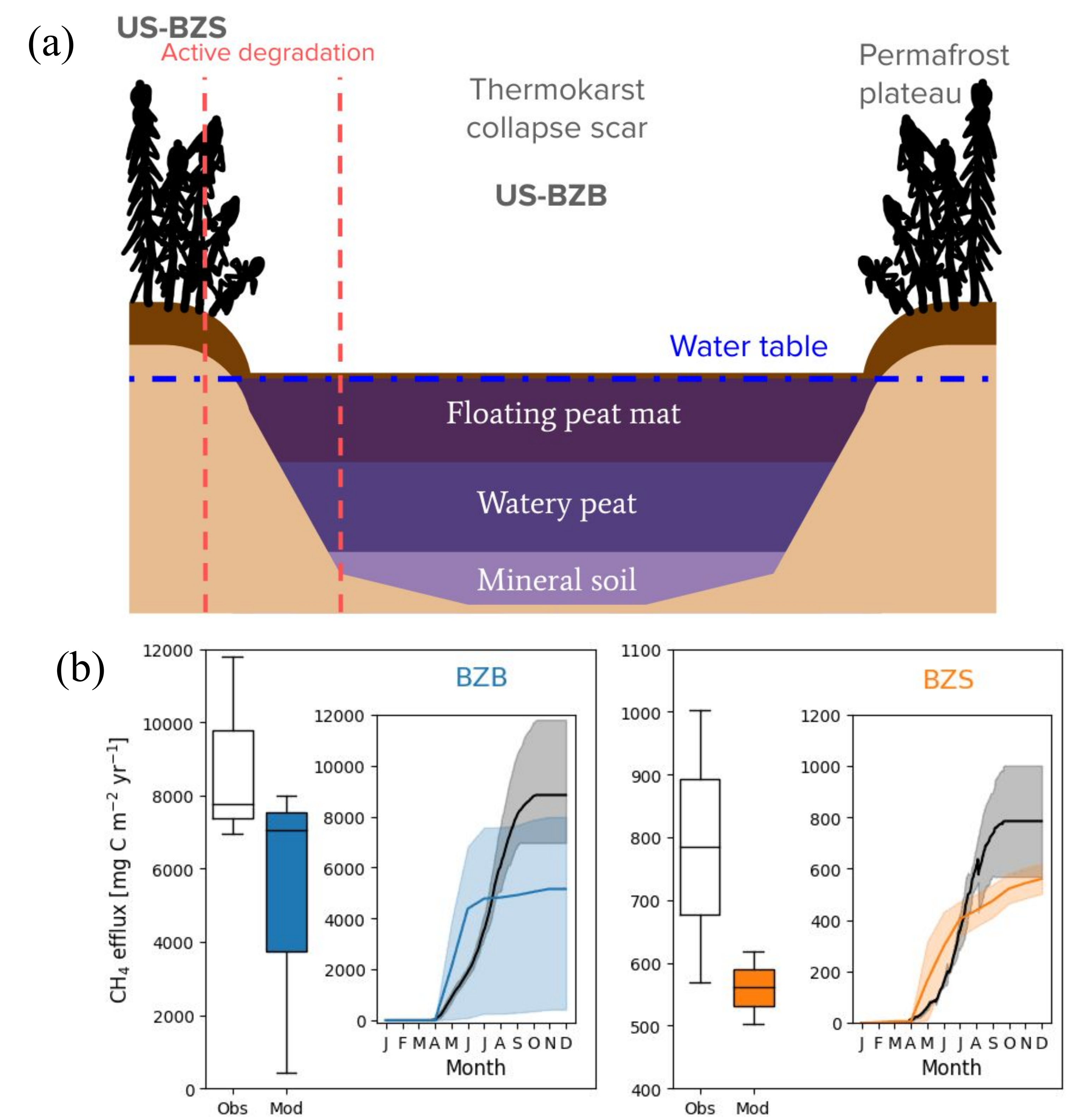

***Figure 4** - (a) Conceptual diagram and (b) observed and simulated annual CH_4 efflux for adjacent US-BZS and US-BZB sites*

Conclusion

We have integrated CH_4 flux dynamics calculations into DVM-DOS-TEM and initiated parameterization, calibration, and benchmarking against two adjacent sites at APEX in the Bonanza Creek Experimental Forest. Further calibration is required to appropriately represent the seasonal increase in CH_4 efflux during the year. There is large seasonal and interannual variability, therefore not only is additional flux and ancillary data essential, but further observations considering individual flux pathways (e.g. plant-mediation) will be highly valuable.

References

Fan, Z., *et al.* (2013), *Glob Change Biol*, 19: 604-620. https://doi.org/10.1111/gcb.12041
Schuur, E., *et al. Nature* 520, 171–179 (2015). https://doi.org/10.1038/nature14338
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