Dances with Microbes: Understanding Greenhouse gas Emissions with Biogeochemical Models

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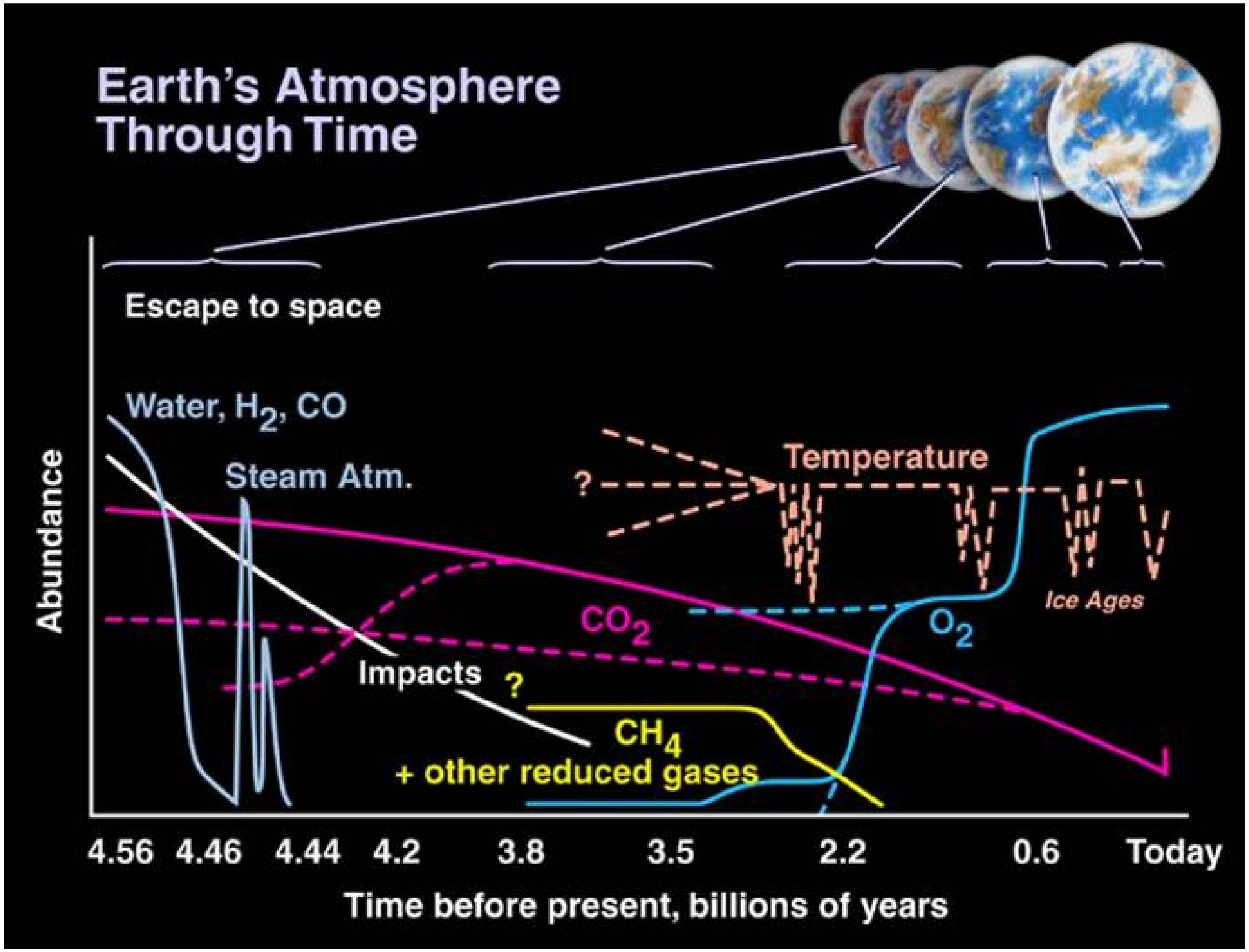
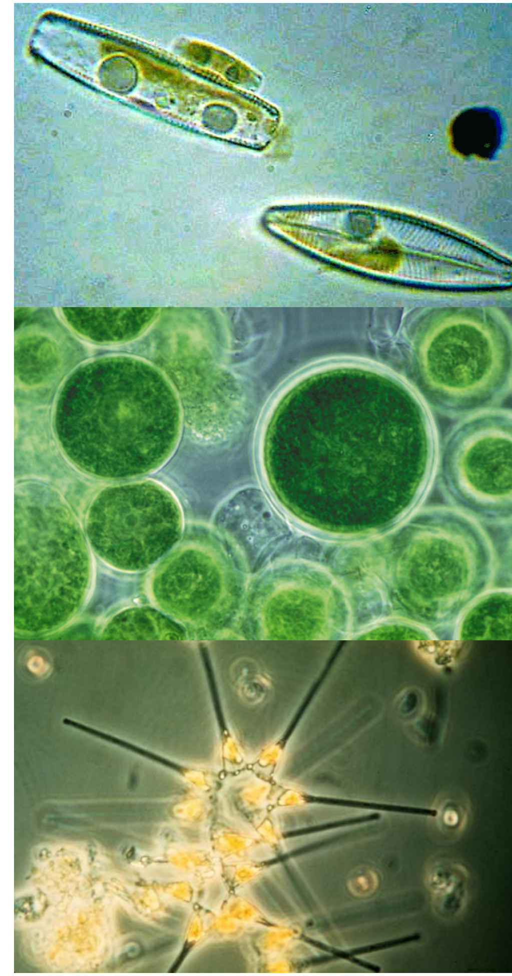
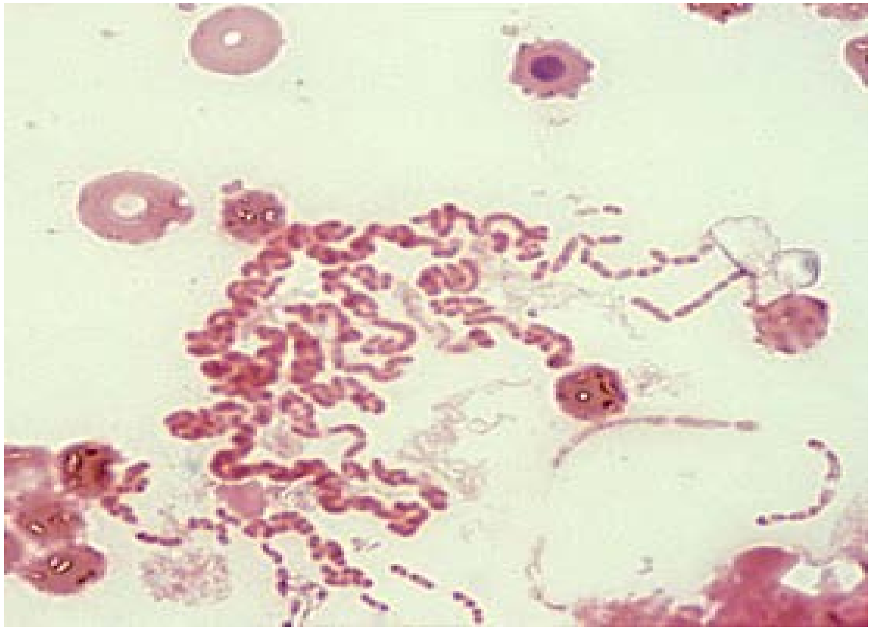
Microbes have been playing a key role in atmospheric evolution

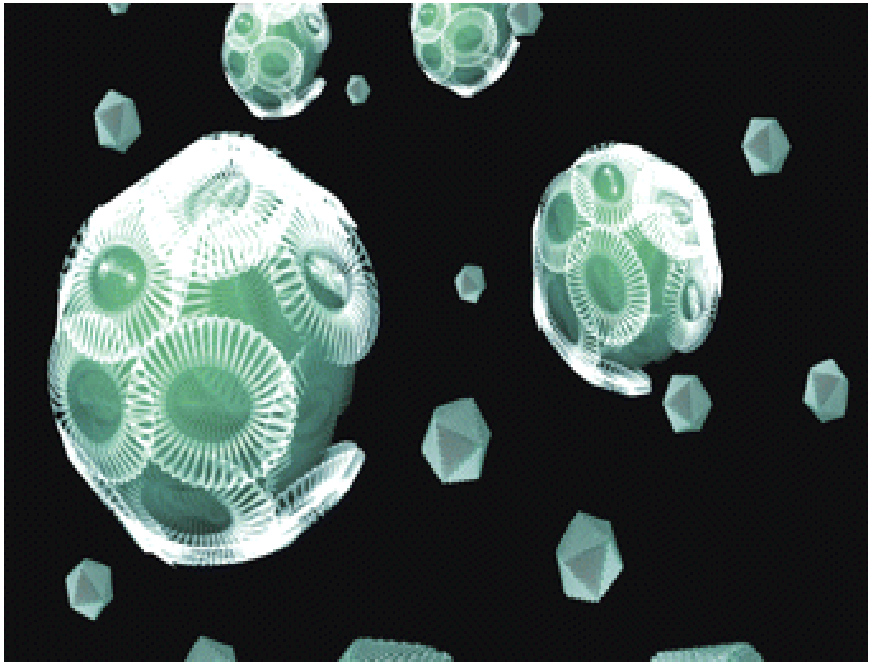




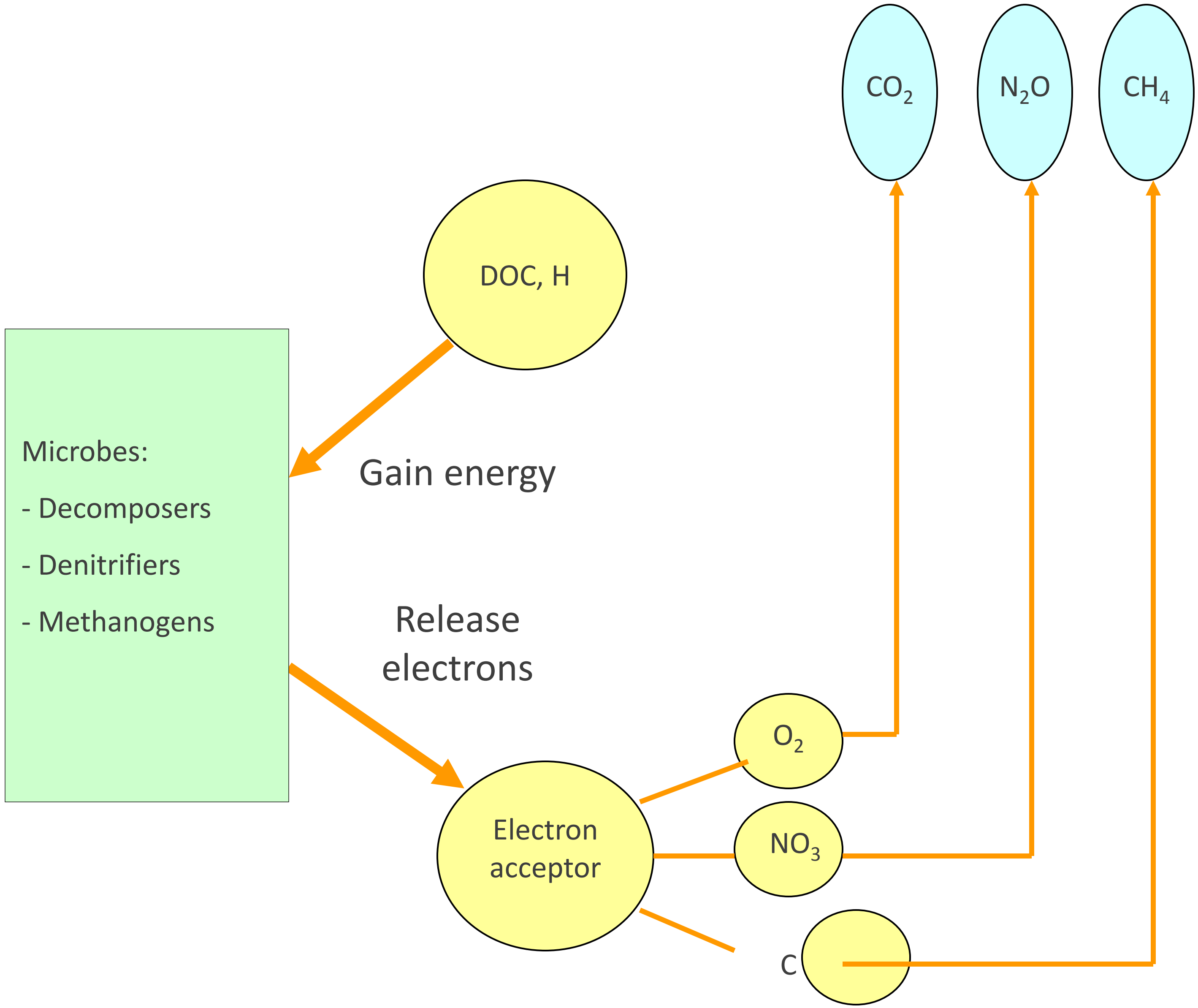


The power of microbes

1. Large reactive surface;
2. Fast reproduction; and
3. Horizontal gene transfer



GHG Production Results from Microbial Survival



The invisible hand in universe: Thermodynamics

Microbes gain energy in the most efficient way

$C + O_2 \longrightarrow CO_2$

(ΔG = -393.51 kJ/mol)

$2C + NO_3 \longrightarrow NO_2 \longrightarrow NO \longrightarrow N_2O \longrightarrow N_2$

(ΔG = -245.23 kJ/mol)

$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O$

(ΔG = -50.75 kJ/mol)

$CH_3COO^- + H^+ \longrightarrow CH_4 + CO_2$

(ΔG = -36 kJ/mol)

Hypotheses for Modeling GHG in DNDC

- CO_2, N_2O and CH_4 are products of oxidation-reduction (redox) reactions through **electron exchange** between electron donors and acceptors though mediated by microbes;

- Occurrence of the electron exchange is determined by the redox potential (Eh) of the environment, which can be quantified with the **Nernst Equation**;

- When the suitable Eh is established, the functional group of bacteria will build up their **full capacity** within several hours or days due to rapid reproduction and horizontal gene transfer;

- When the microbial capacity is built up, the reaction rate will be controlled by the concentrations of the relevant nutrient substrates based on the **Michaelis-Menten Equation**.

Two Equations Cored in DNDC

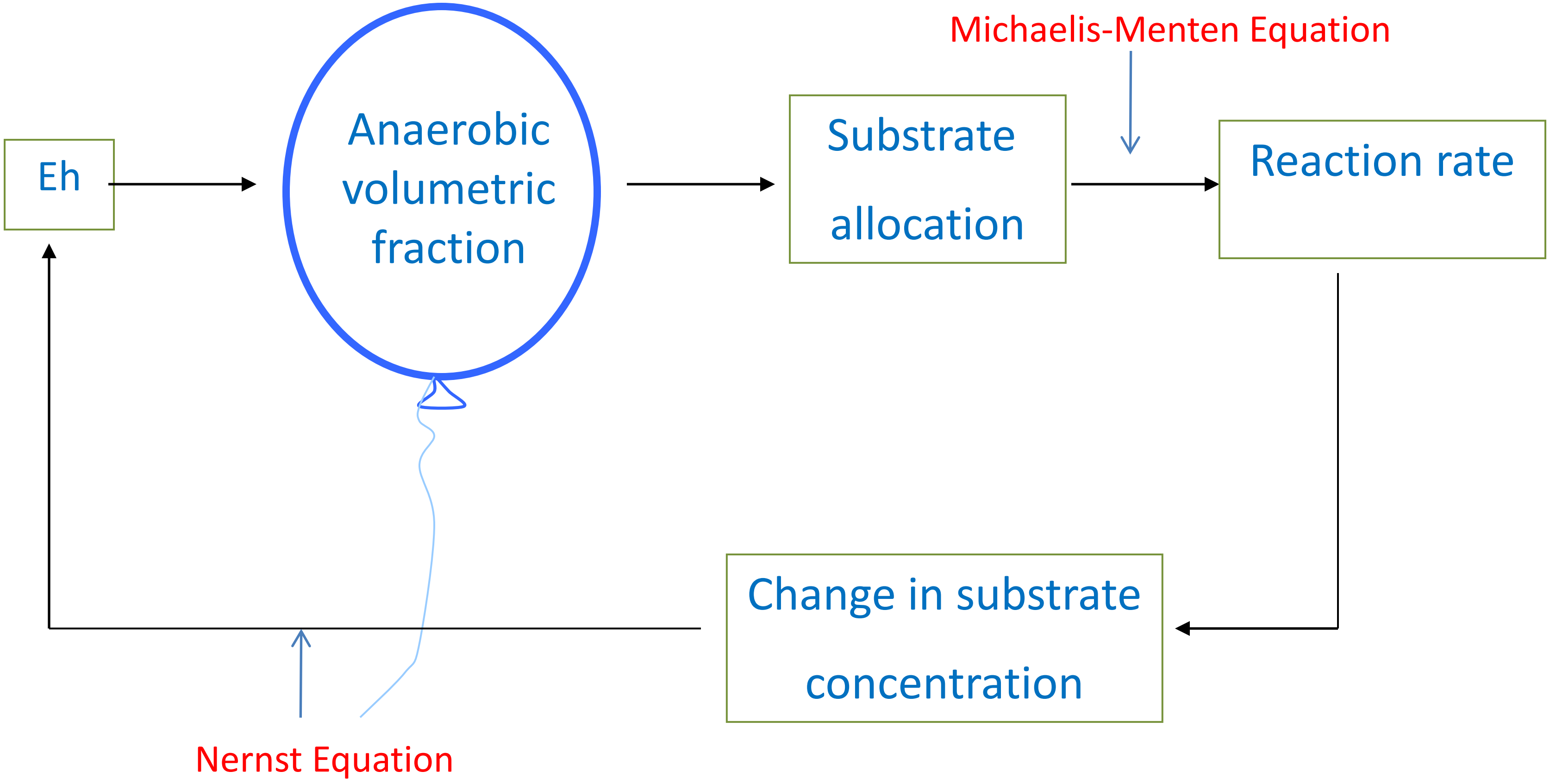
- The **Nernst Equation** (thermadynamics):

$$Eh = Eo + RT/nF \cdot \ln([OX]/[RE])$$

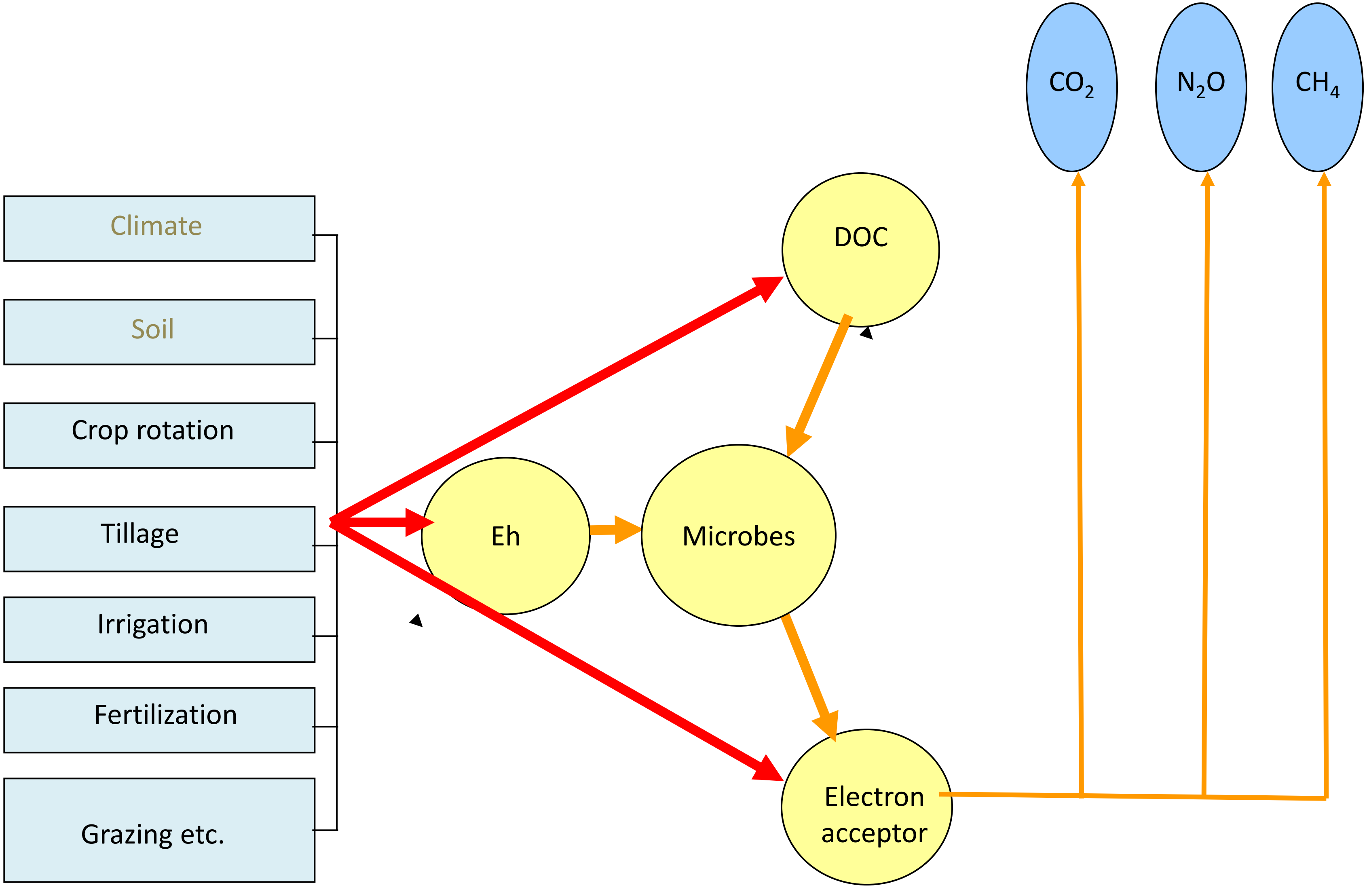
- The **Michaelis-Menten Equation** (kinetics):

$$R = Rmax \cdot DOC/(Ka+DOC) \cdot OX/(Kb+OX)$$

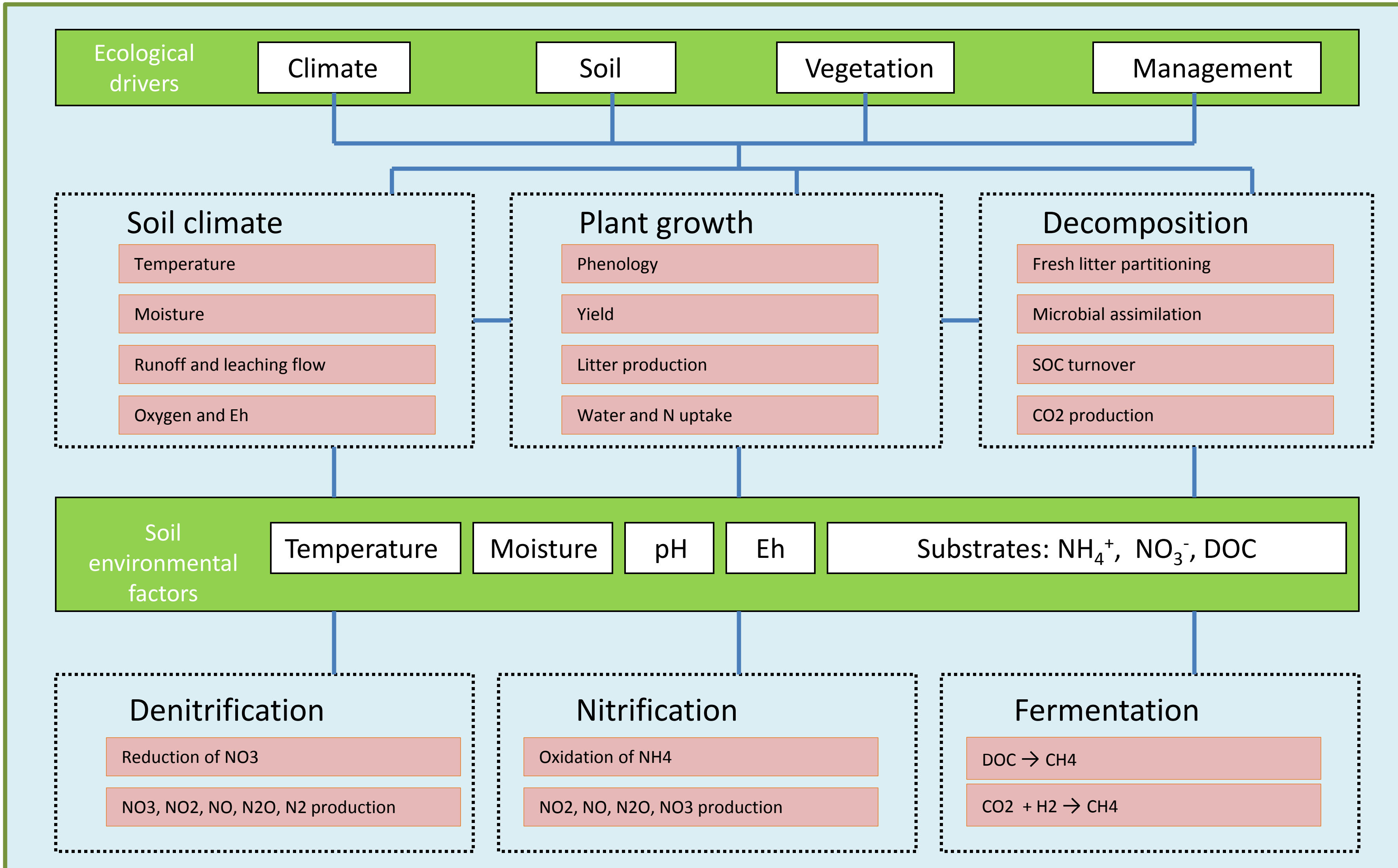
An “anaerobic balloon” intergrating Nernst and Michaelis-Menten Equations in DNDC



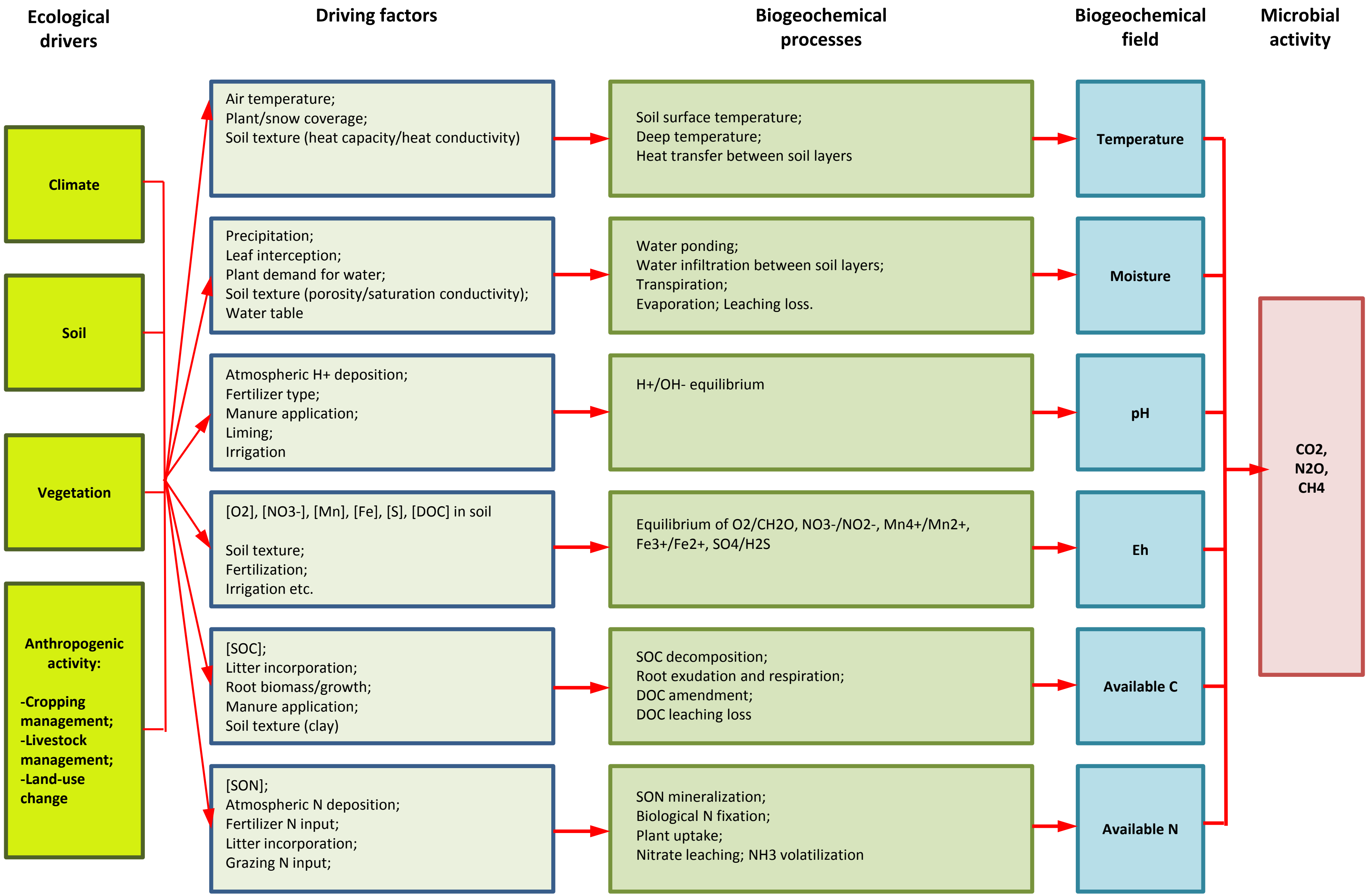
Linking human activity to GHG production



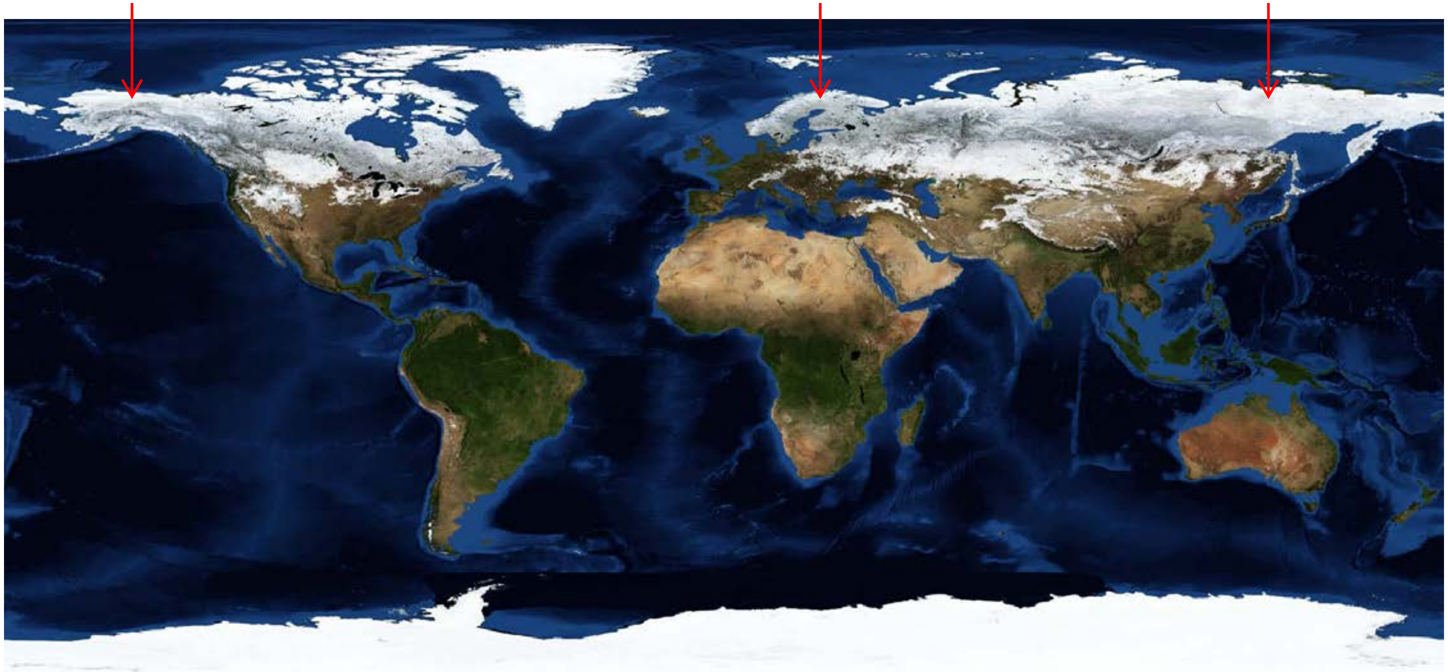
DNDC Structure



Biogeochemistry in DNDC

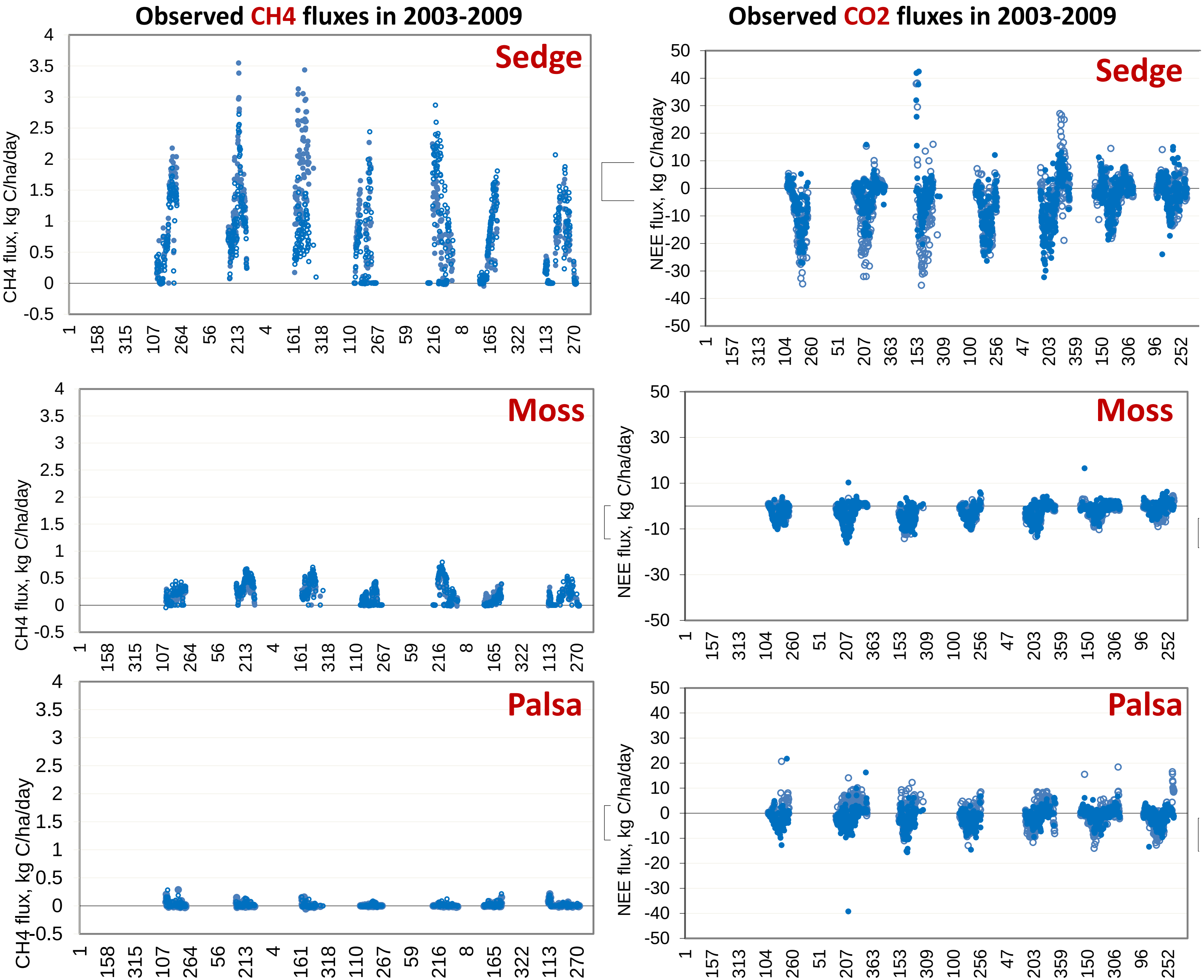


NASA Project: Global Warming in High Latitude Regions



Warming trend in permafrost soils

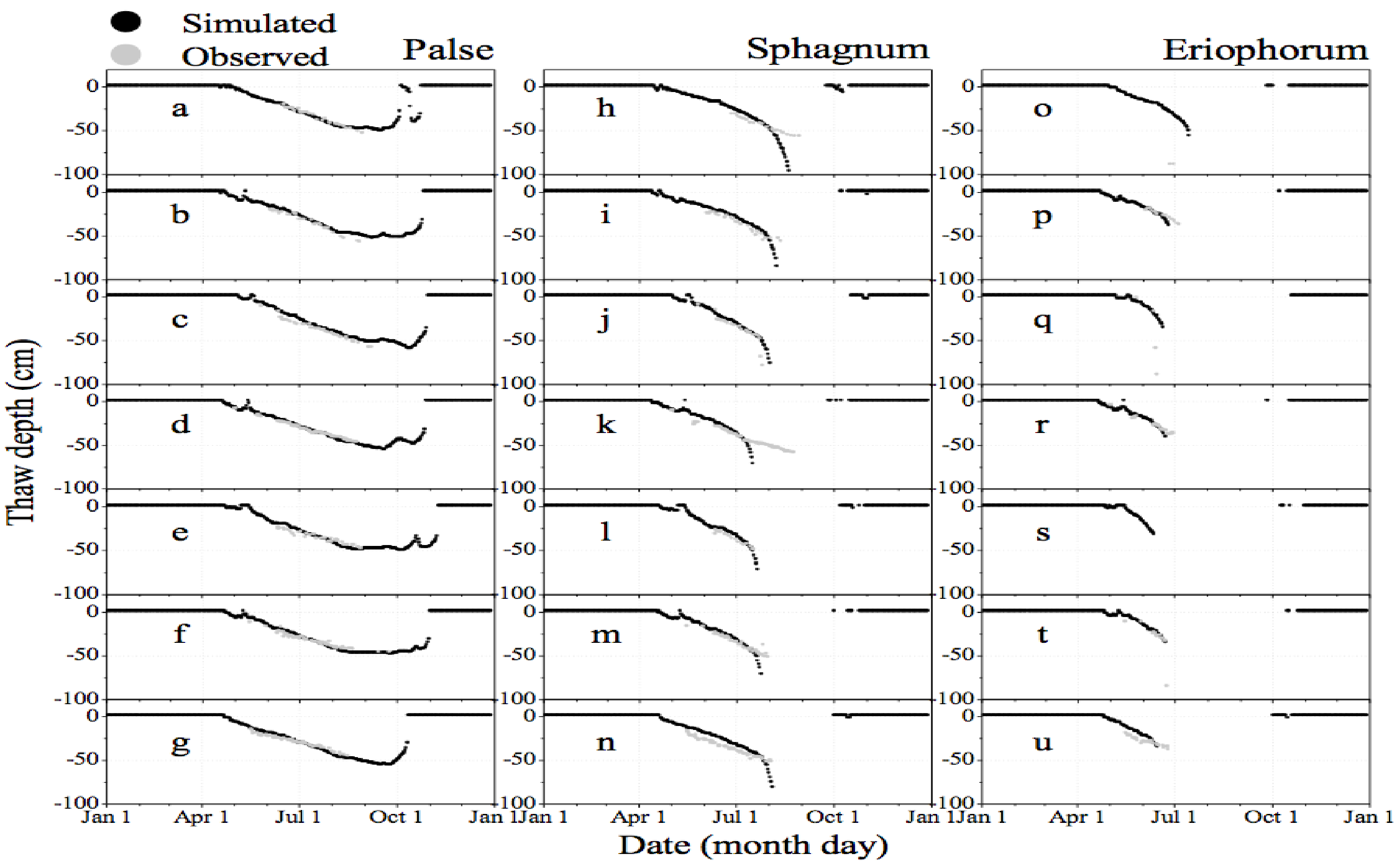
Field Measurement in Stordalen, Sweden in 2003-2009



(C gases from a wetland at **Stordalen, Sweden**, data from Patrick Crill in 2011)

DNDC Simulation 1: Soil Climate

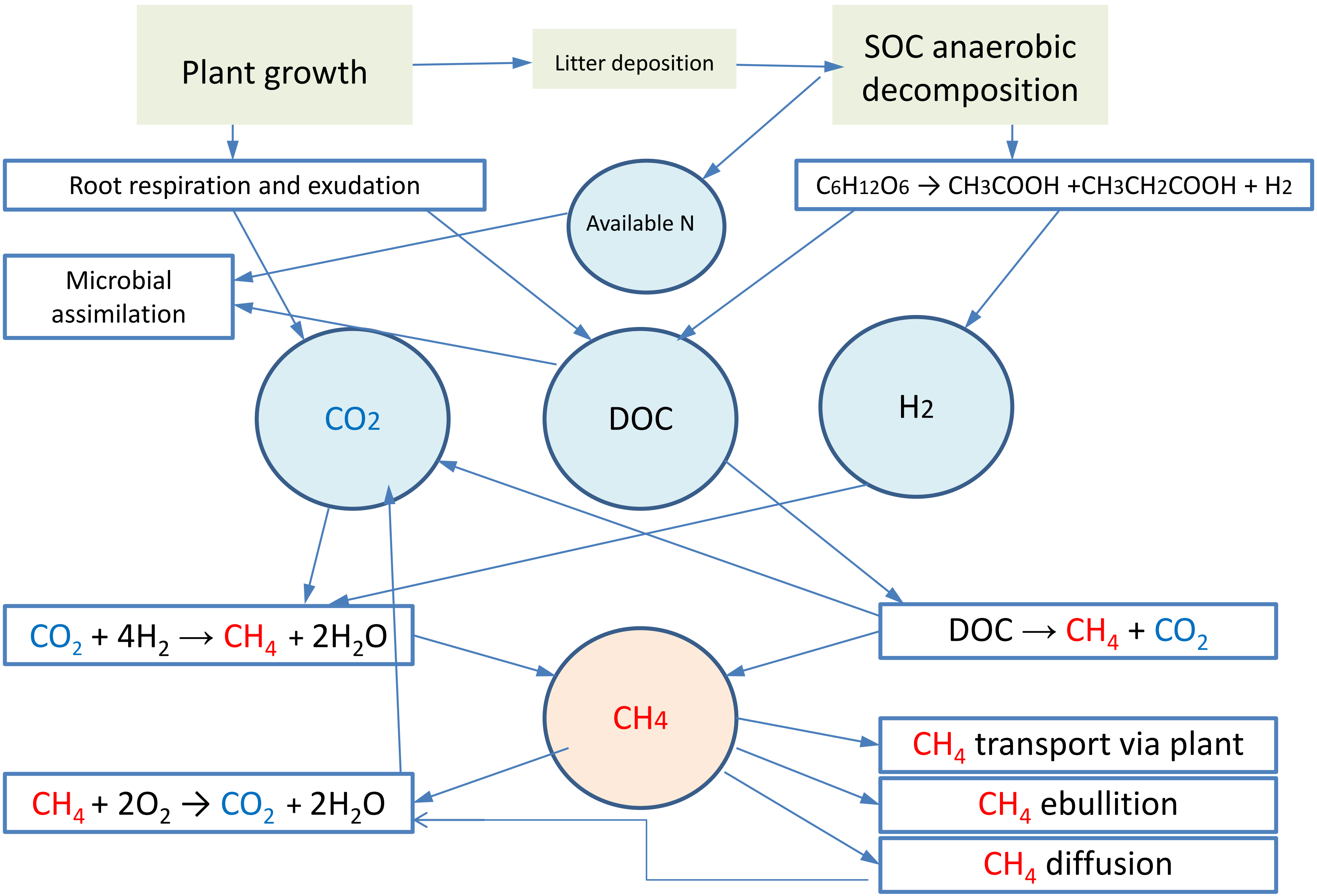
(Soil thawing depth)



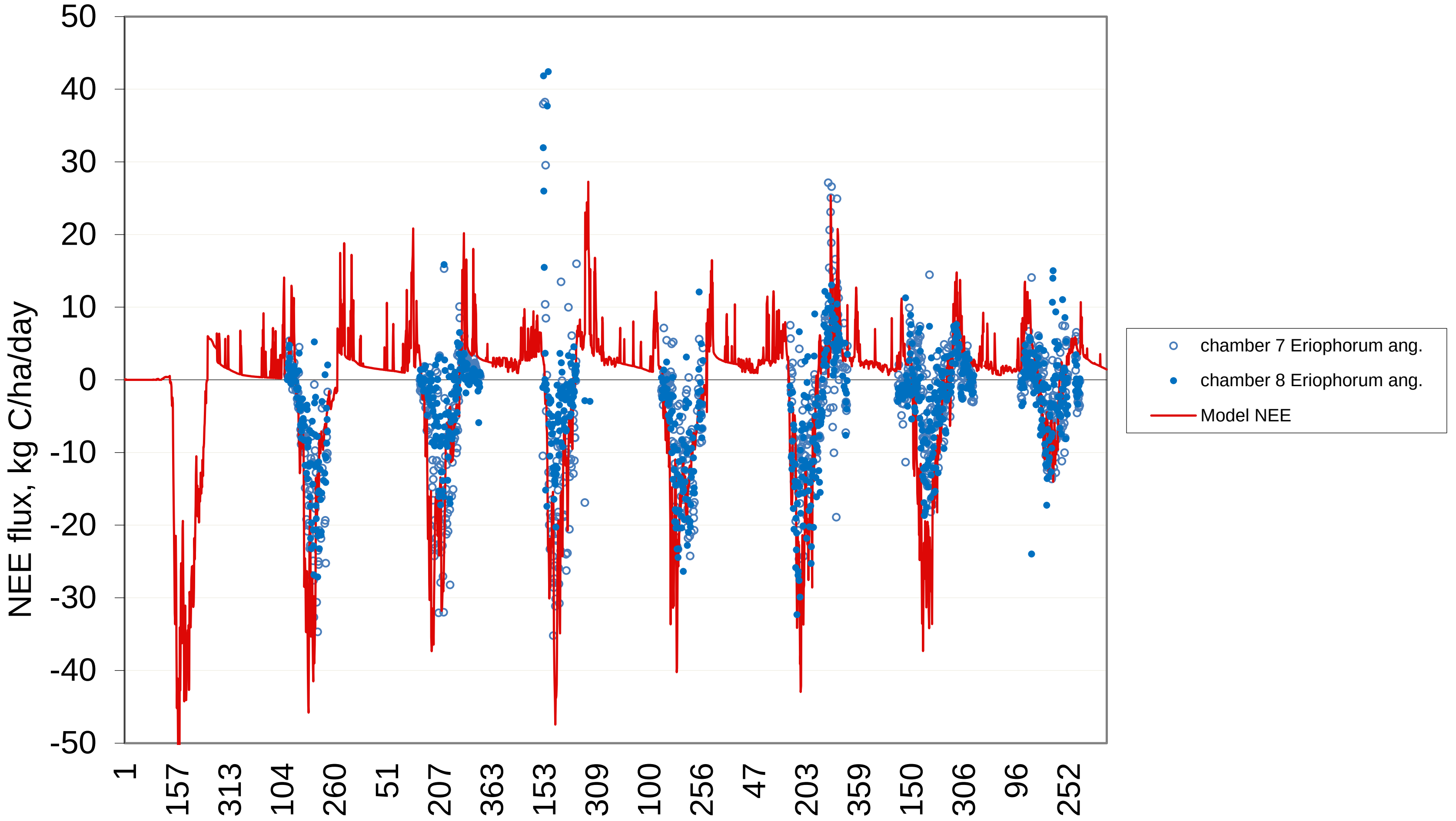
DNDC Simulation 2: Plant Growth
(Plant Paramerization)

Plant	Max biomass production (kg C/ha/yr)	Shoot/root	C/N ratio	TDD (degree C)	N fixation index	Vascularity
Sedge (Eriophorum)	3000	0.35/0.65	100	1500	1.1	1
Moss (Sphagnum)	1500	0.95/0.05	120	1500	1.1	0
Shrub (Palsa)	1000	0.5/0.5	100	1500	1.1	0

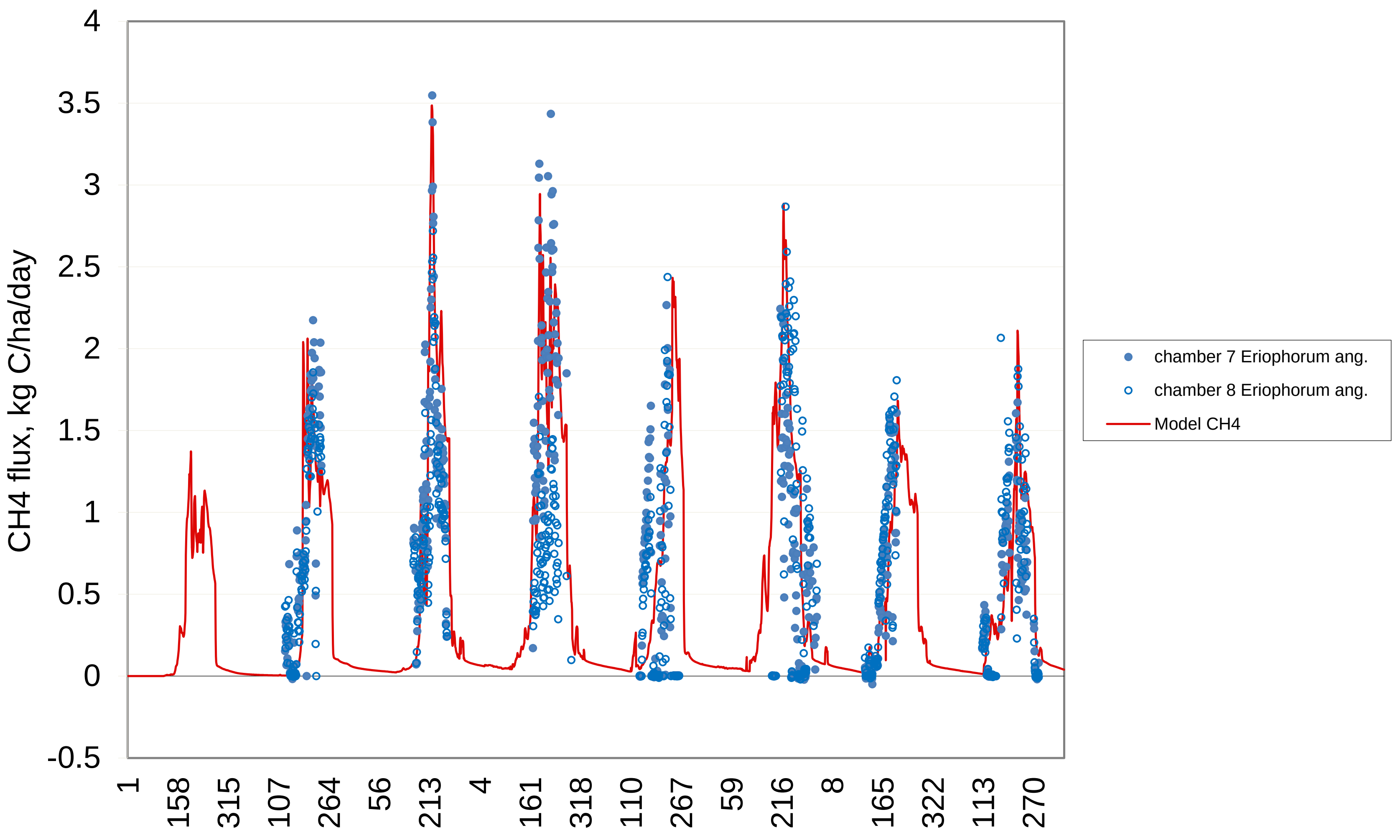
DNDC Simulation 3: Soil C Dynamics



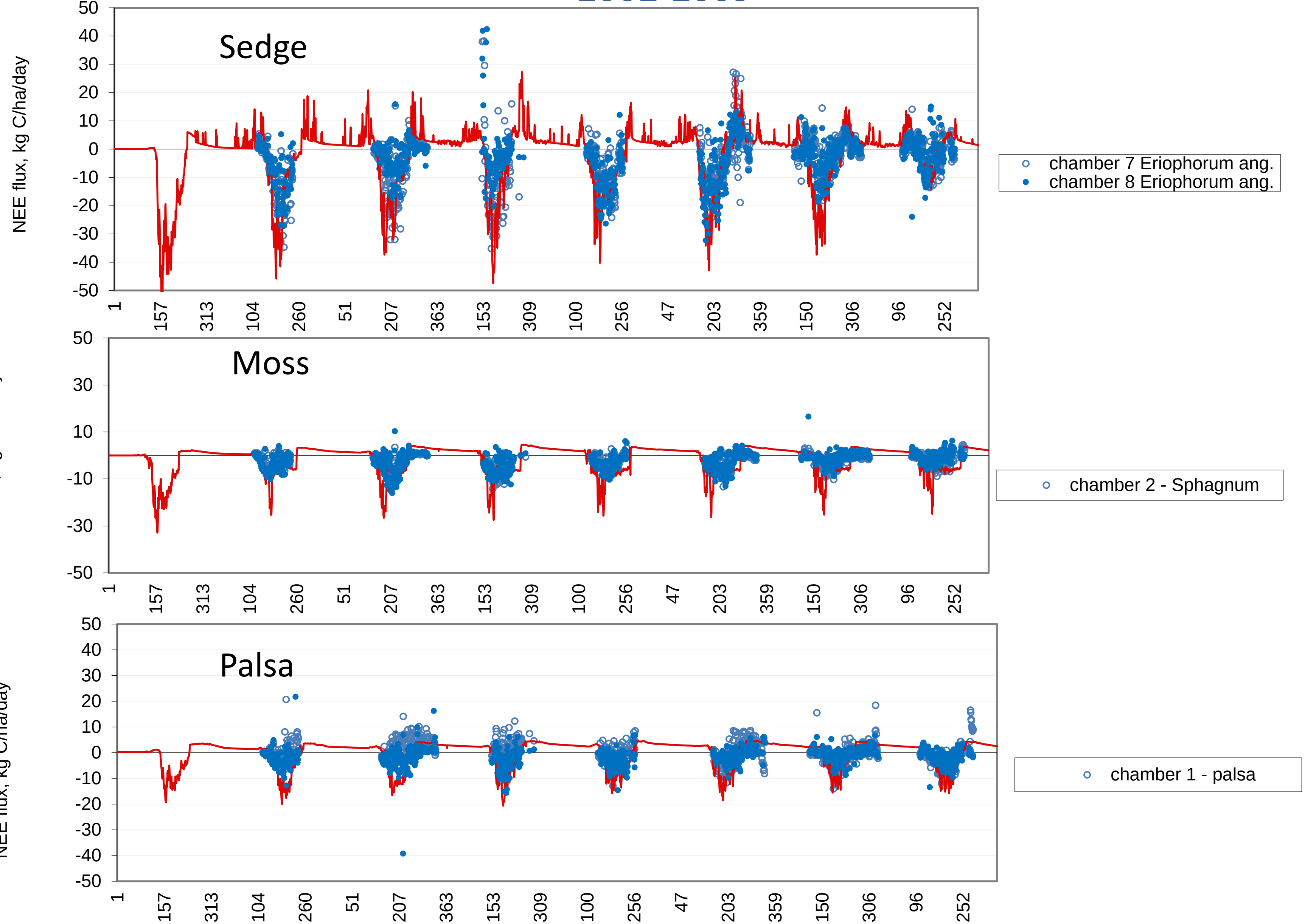
Measured and modeled ecosystem CO2 (NEE) fluxes from sedge plot at Stordalen, Sweden in 2002-2009



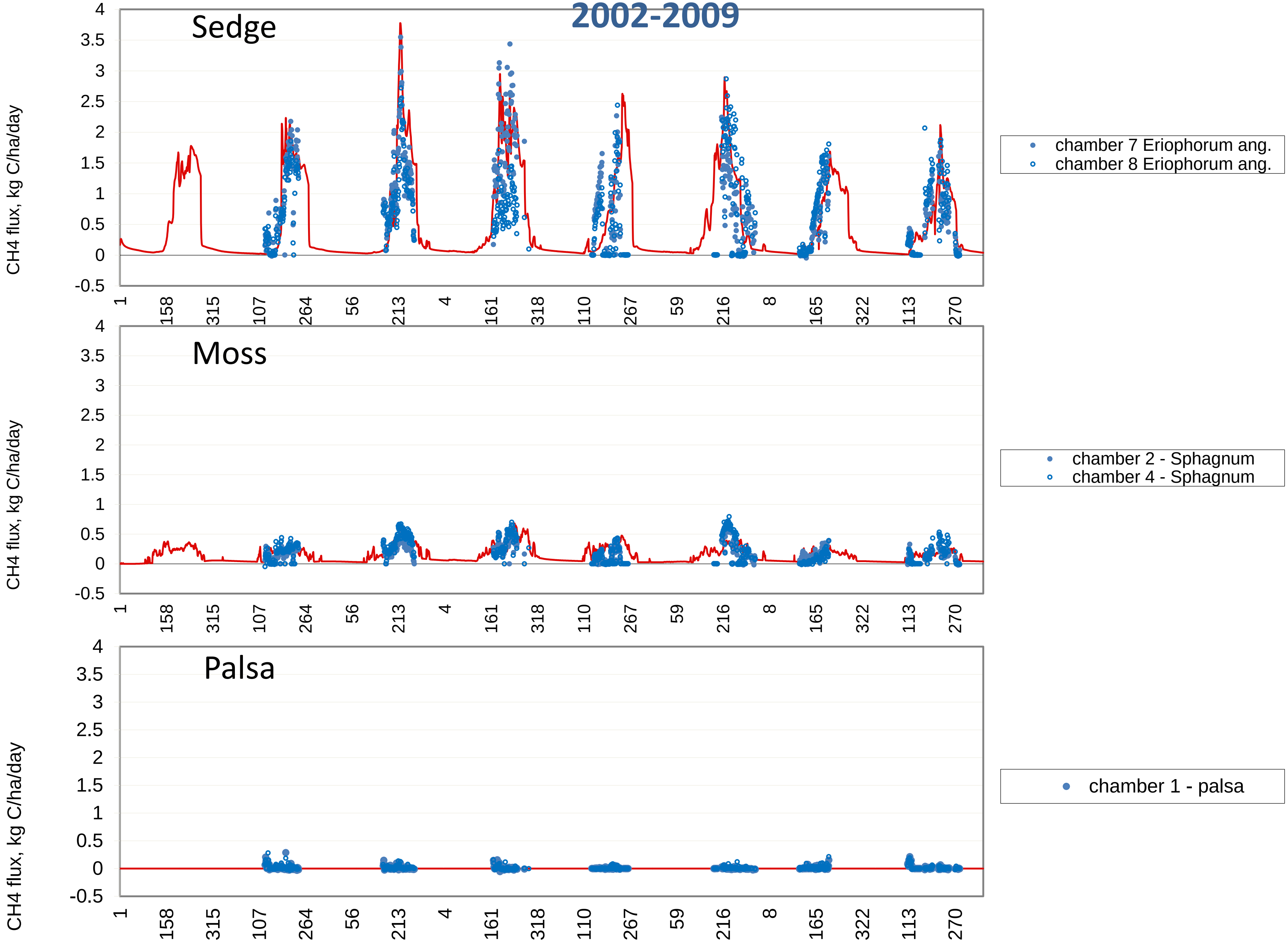
Measured and modeled CH4 fluxes from sedge-dominated plot at Stordalen, Sweden in 2002-2009



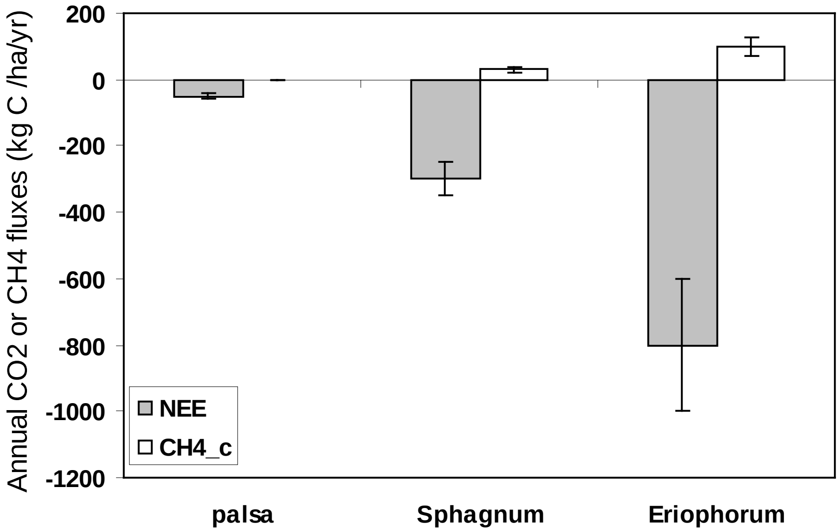
Measured and modeled CO2 fluxes from wetland at Stordalen, Sweden in 2002-2009

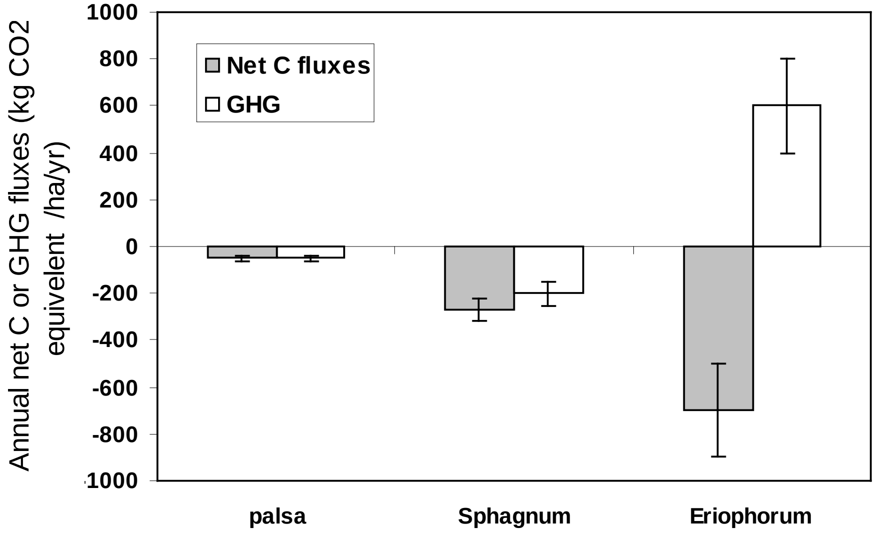


Measured and modeled CH4 fluxes from wetland at Stordalen, Sweden in 2002-2009



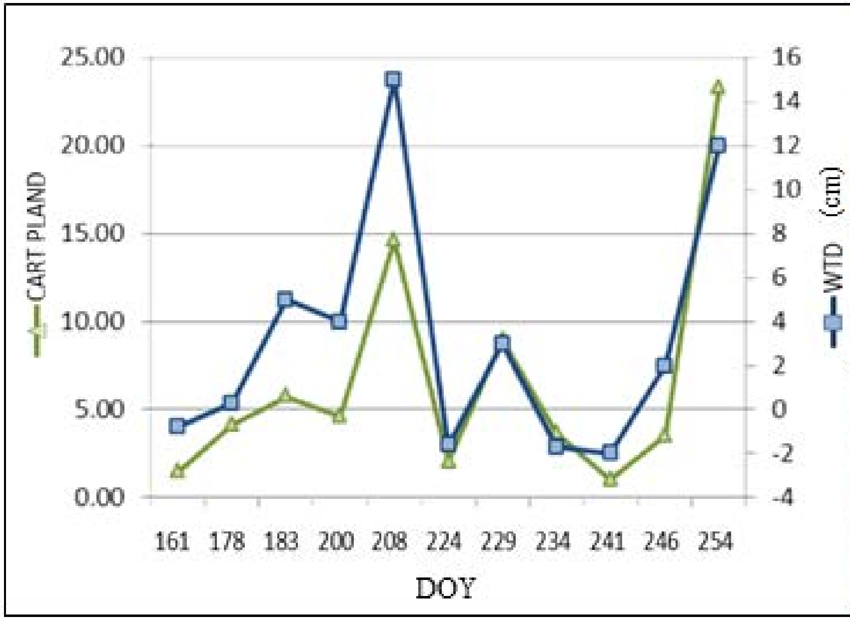
Modeled C and GHG Fulxes at Stodalen, Sweden

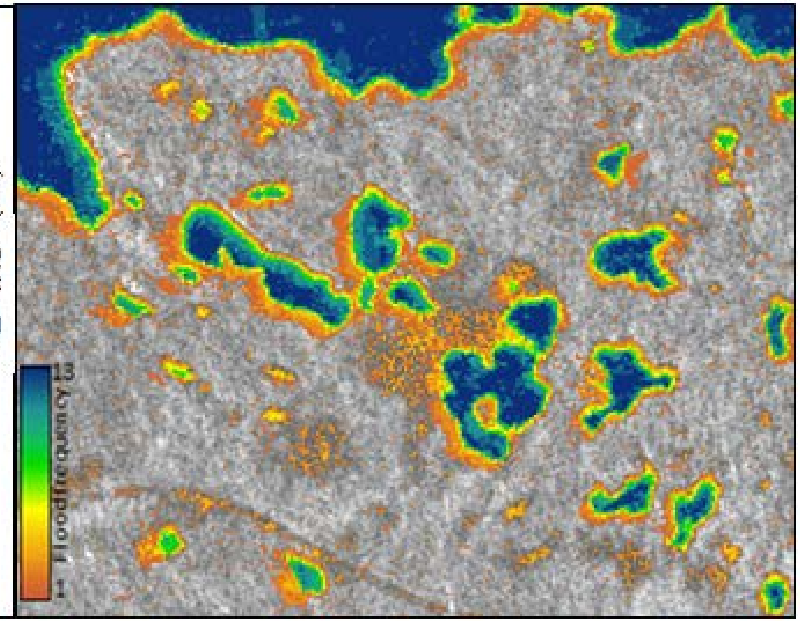




1. **Climate warming has significant impacts on the C balance of the tested permafrost ecosystem;**
2. **The warming trend turns the permafrost ecosystem into a stronger atmospheric C sink;**
3. **However, the increased CH4 emissions increase the radiative forcing impacts on climate.**

DNDC Simulation 4: Linking DNDC to Remote Sensing Data for Upscaling





Hydroperiod mapping from fused PALSAR finebeam and Lidar over Stordalen, Sweden mire. The CART flood likelihood map Percent of Landscape (PLAND) metric had strong correspondence to Water Table Depth (WTD) measurements at the mire across the aggregated DOY (different years) calendar for corresponding periods. The flood intensity map indicates the percent a pixel was observed as flooded and as an indicator of soil moisture.

Discussions

On this planet, greenhouse gas emissions are driven by biogeochemical processes with microbial and human activities involverd in conjunction. To mitigate GHG emissions, no matter where, we have to learn how to dance with the microbes.

Biogeochmical modeling provides a powerful tool to predict interactions among human activity, microbial behaviors and GHG emissions for mitigation at site, regional or global scale.