Dances with Microbes: Modeling Greenhouse gas Emissions from Terrestrial Ecosystems

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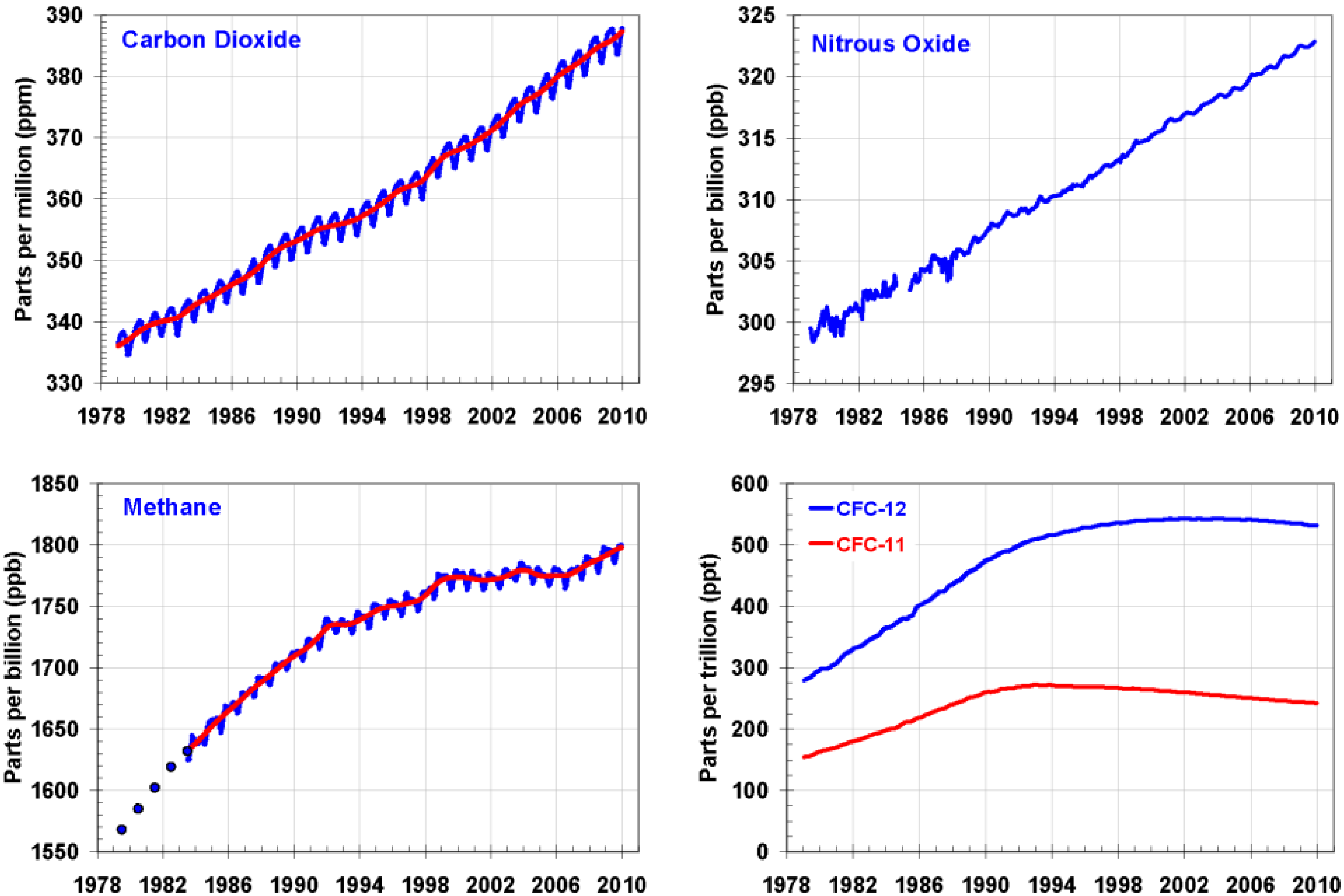
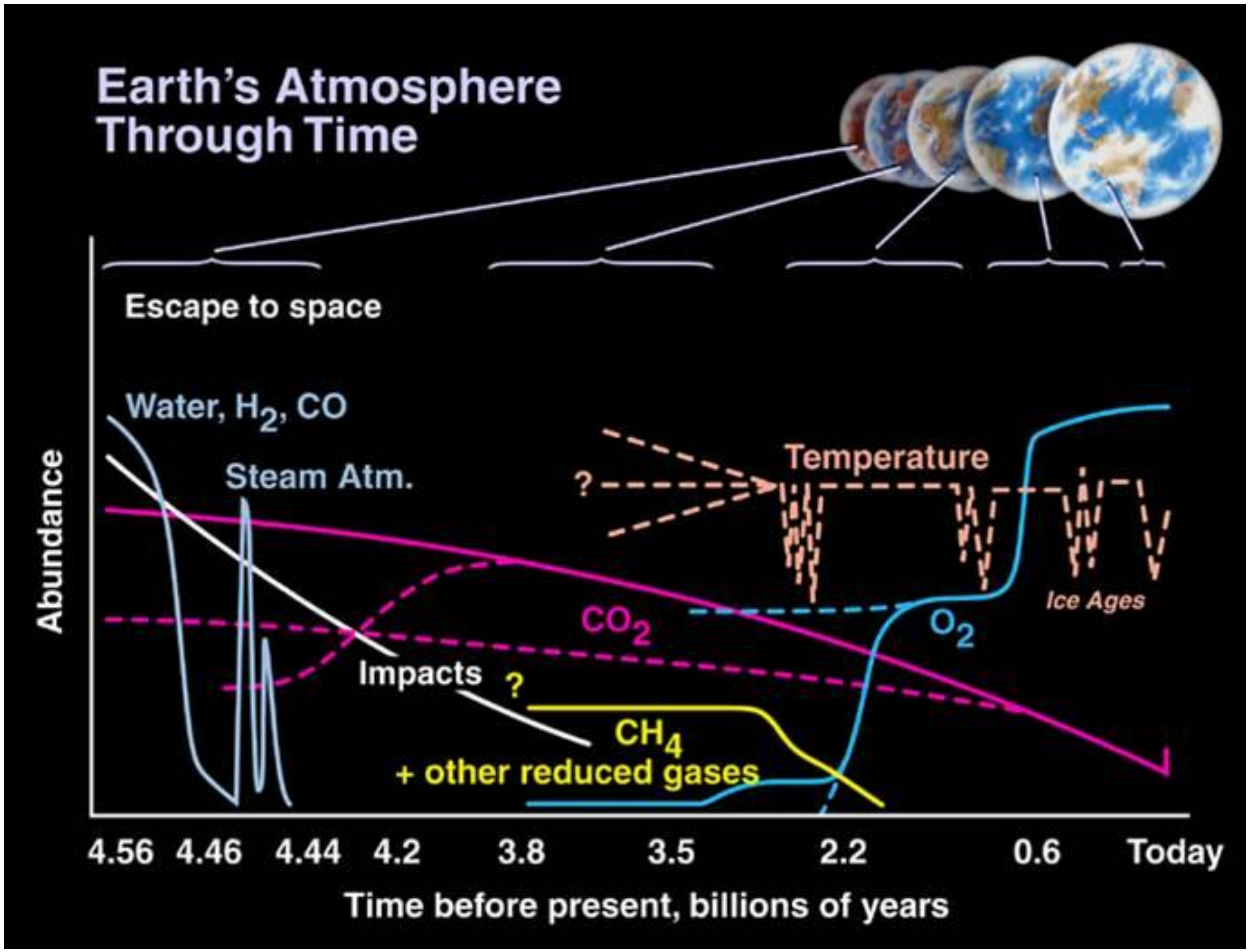
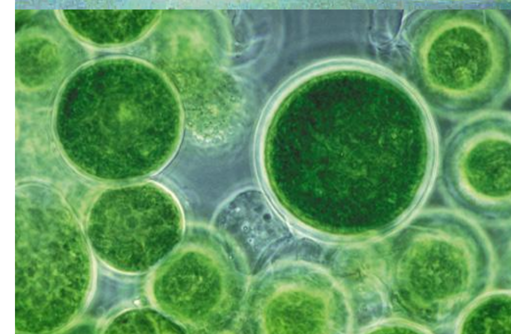
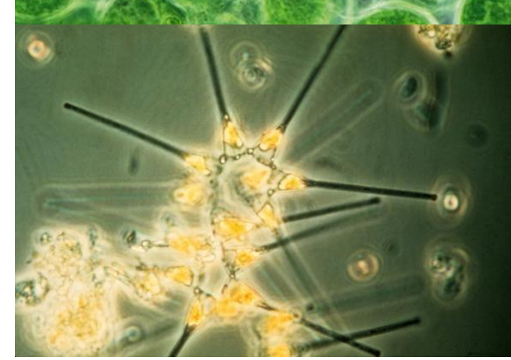
Major Greenhouse Gas Trends



Microbes have been playing a key role in the atmospheric evolution

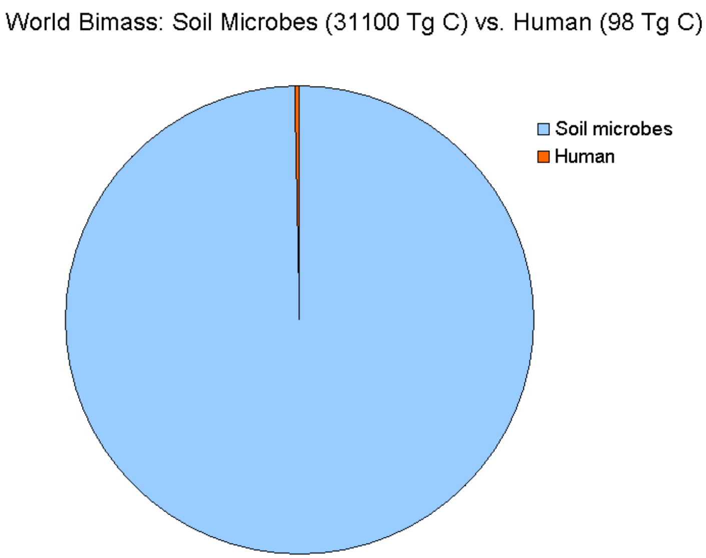


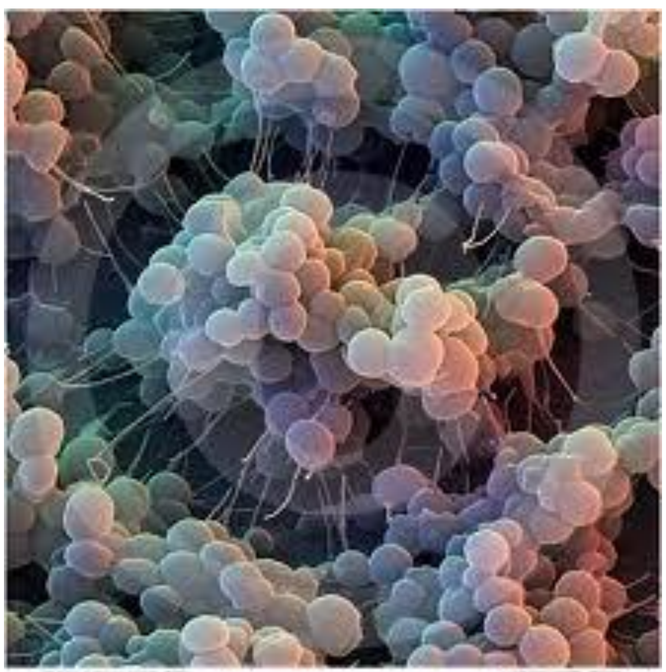




The power of microbes

1. Large mass;
2. Large reactive surface;
3. Fast regeneration; and
4. Horizontal gene transfer





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 Microbe-Mediated GHGs

- CO2, N2O and CH4 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 growth 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.

Equations for Quantifying Microbe-Mediated GHG Production

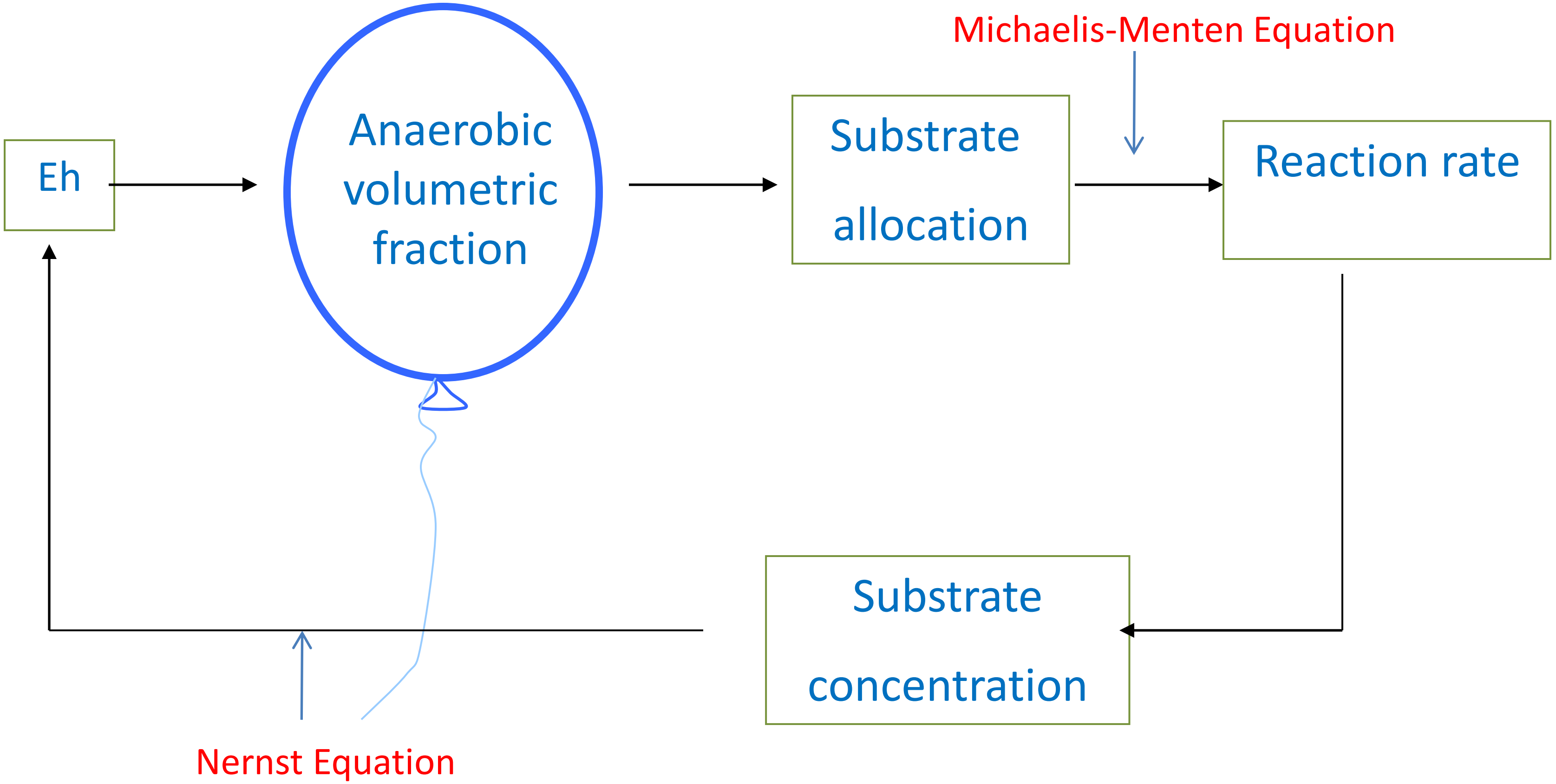
- The **Nernst Equation** (thermadynamic s):

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

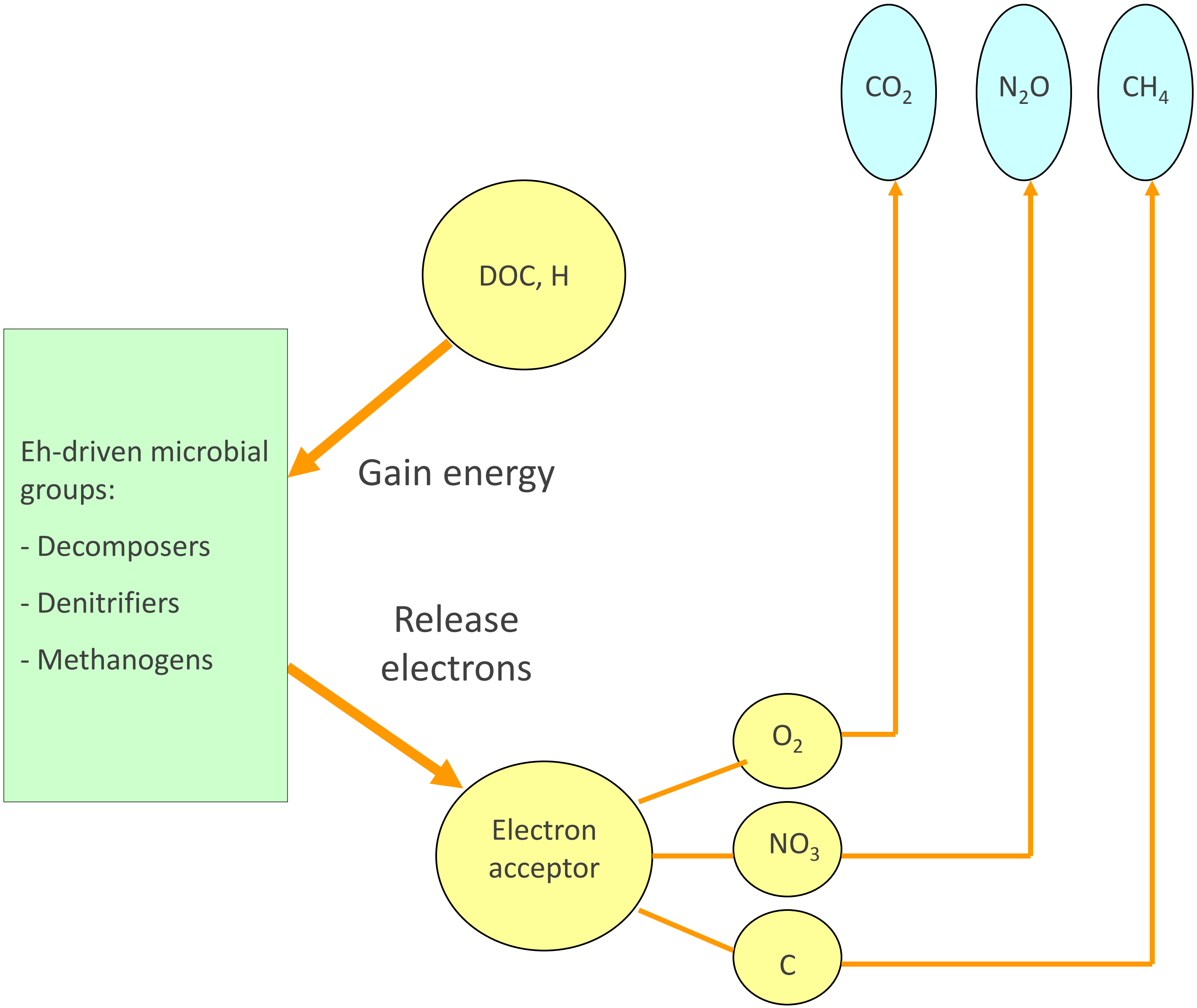
- The **Michaelis-Menten Equation** (kinetics):

$$R = Rmax * DOC/(Ka+DOC) * RE/(Kb+RE)$$

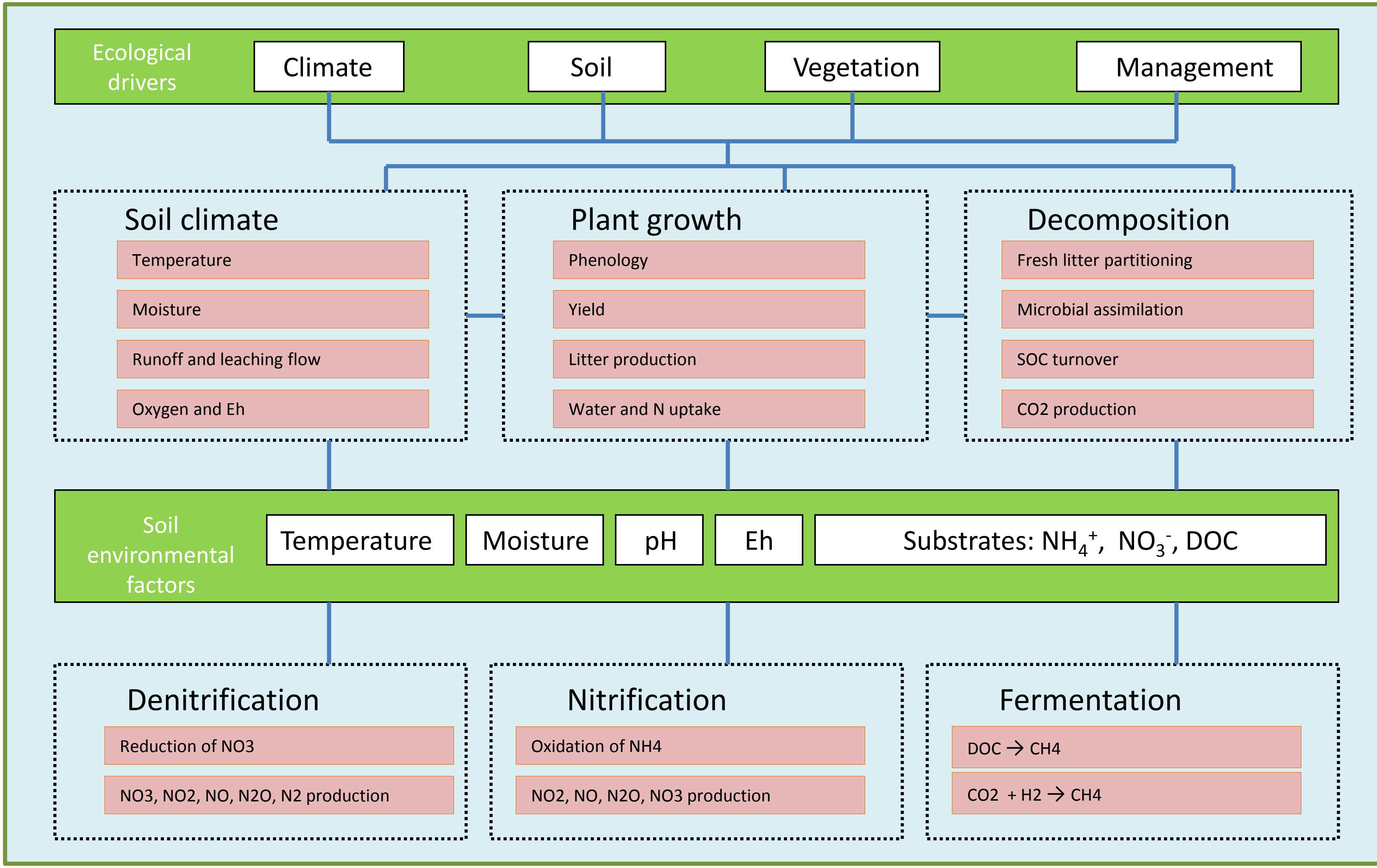
The Algorithm Integrating the Nernst and Michael-Menten Equations in DNDC



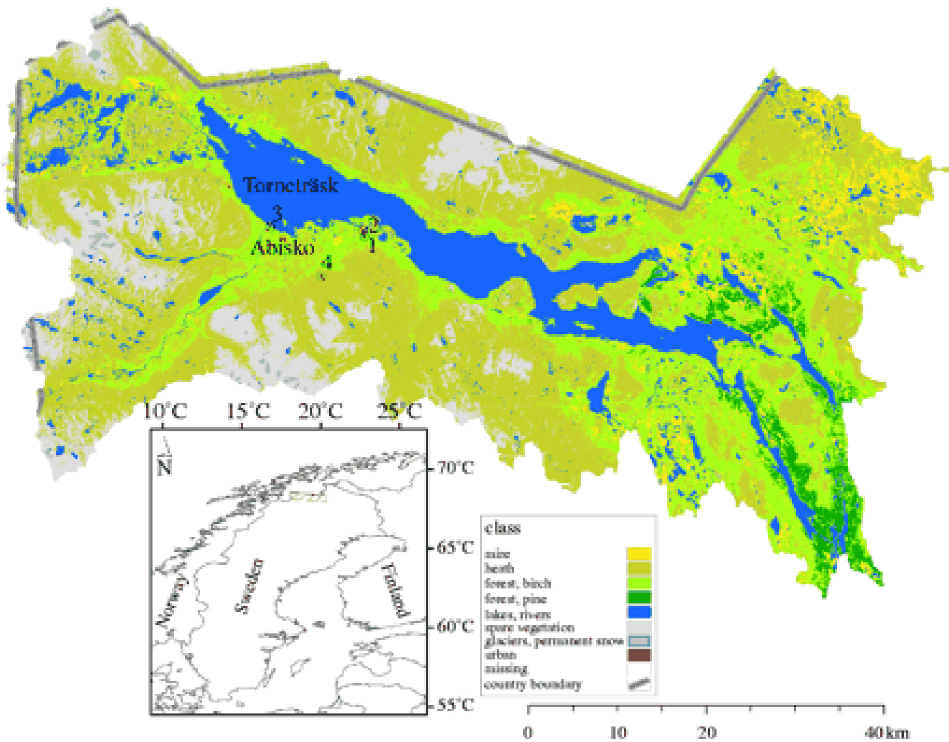
GHG Production Results from Microbial Survival



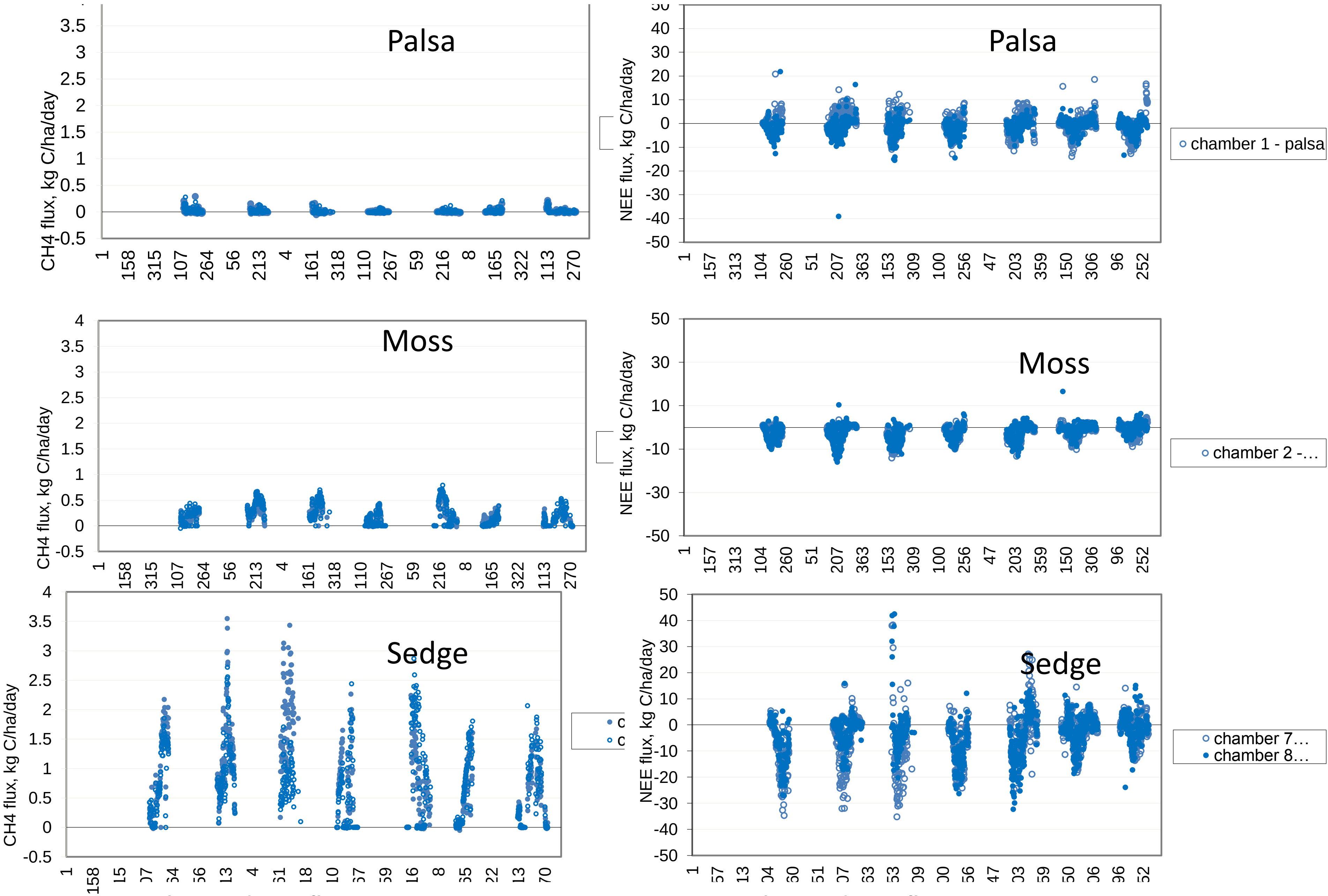
DNDC simulates soil climate, plant growth and soil chemistry to provide context for GHG simulations



Global warming at permafrost soils in Stordalen mire, Sweden



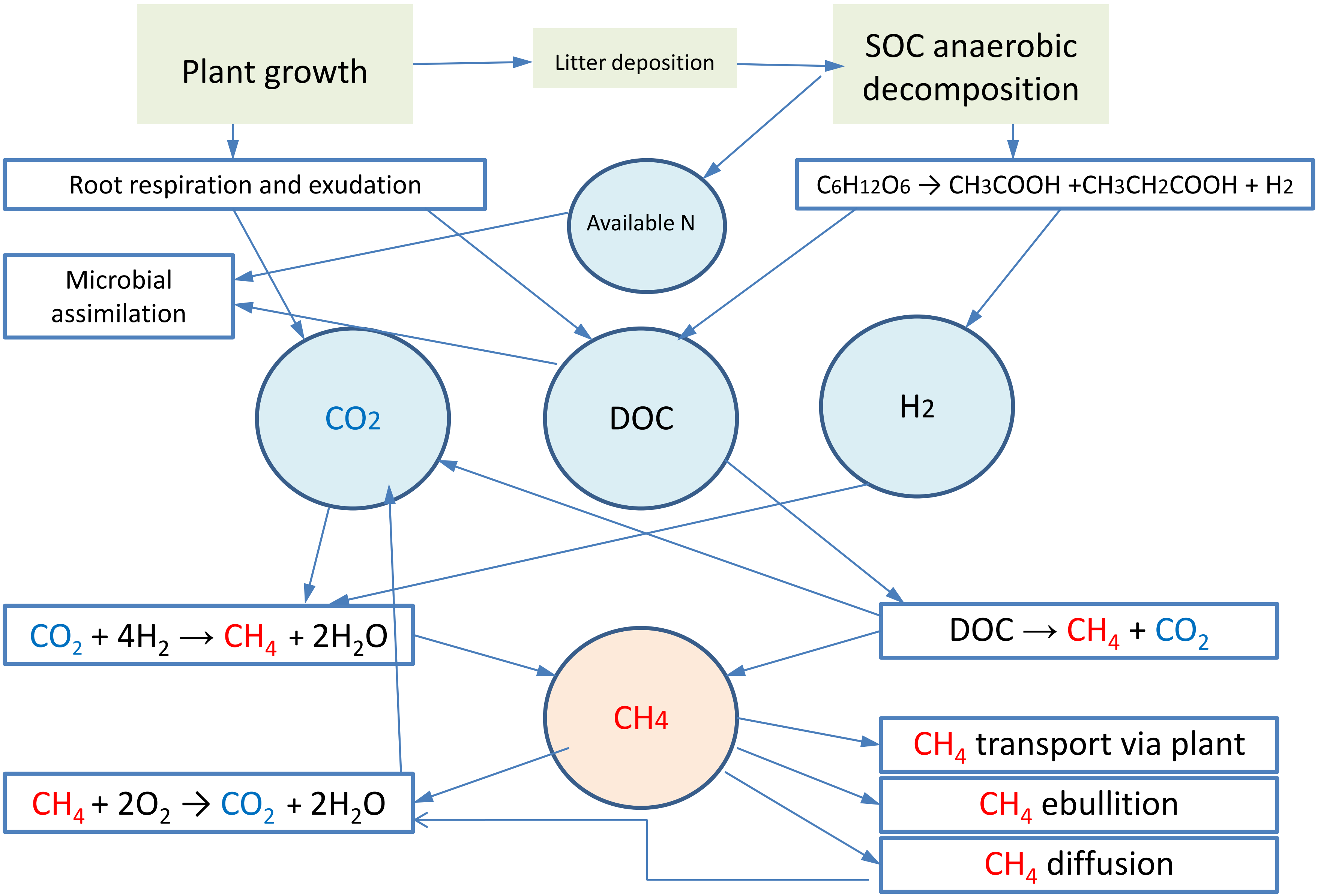
C gases from a wetland at Stordalen, Sweden (data from Patrick Crill in 2011)



Observed CH4 fluxes in 2003-2009

Observed CO2 fluxes in 2003-2009

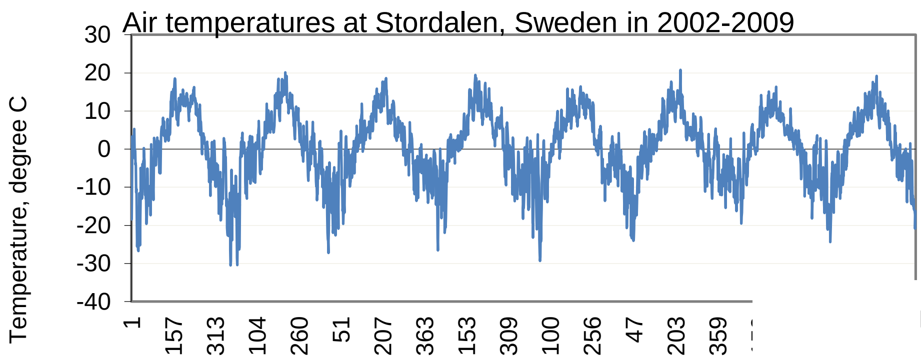
Anaerobic C biogeochemistry embedded in DNDC



Parameters for Stordalen Plants

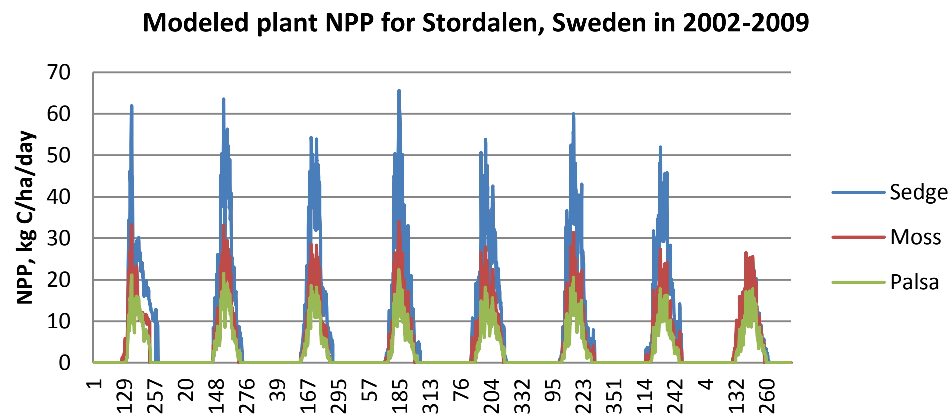
Plant	Max biomass production (kg C/ha/yr)	Shoot/root	C/N ratio	TDD (degree C)	N fixation index	Vascularity
Sedge (Eriophorum)	3000	0.35/0.65	100	1500	1.1	1
Moss (Sphagnum)	1500	0.95/0.05	120	1500	1.1	0
Shrub (Palsa)	1000	0.5/0.5	100	1500	1.1	0

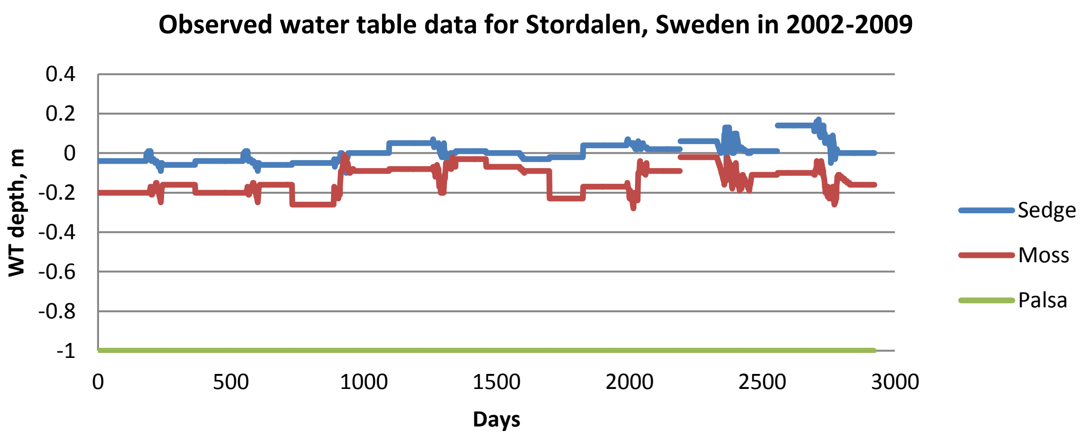
Air temperature, water table and vegetation biomass at Stordalen, Sweden in 2002-2009



Air temperature

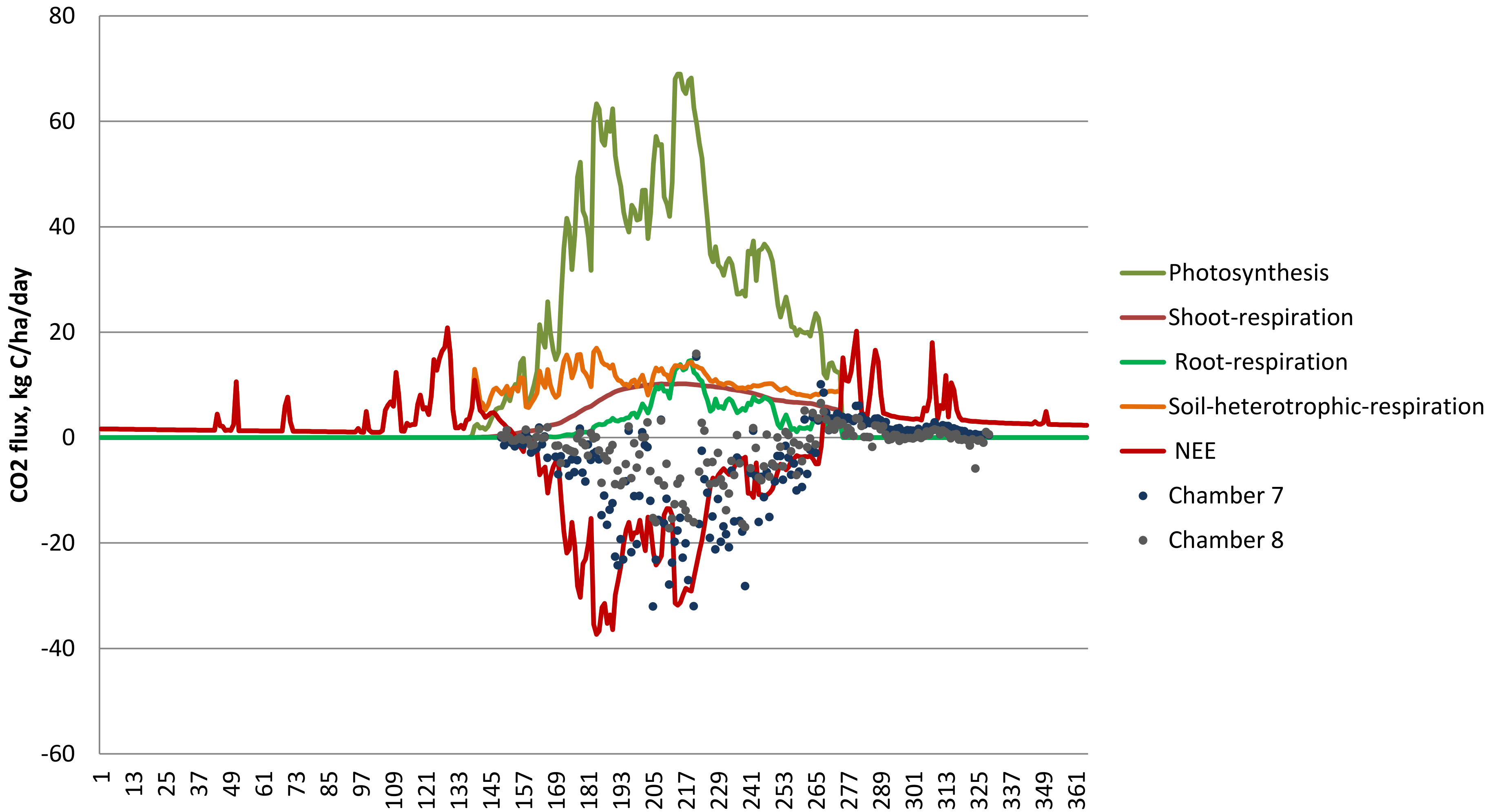
Vegetation NPP



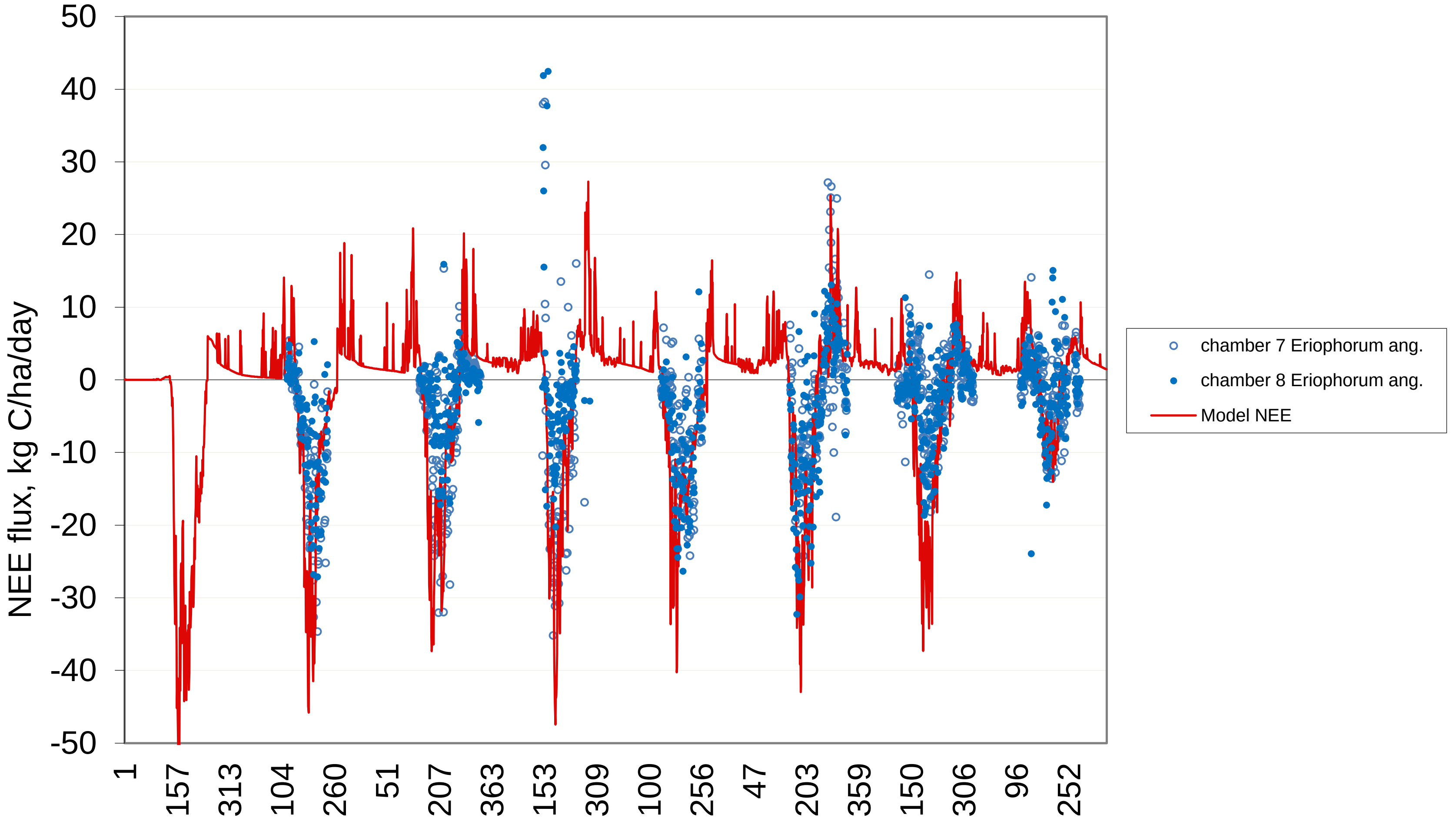


Water table

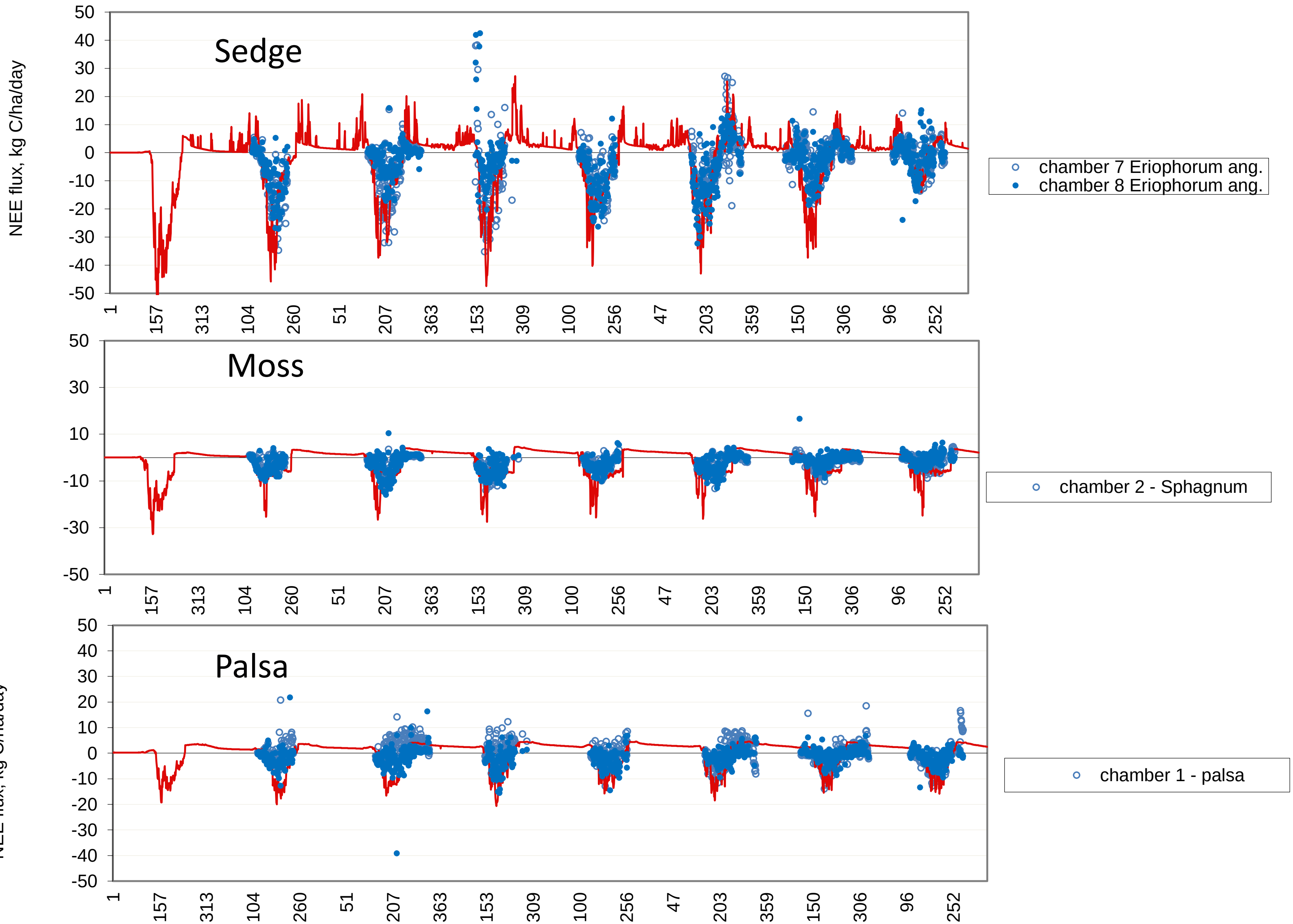
Measured and modeled ecosystem CO2 fluxes in sedge plot at Stordalen, Sweden in 2004



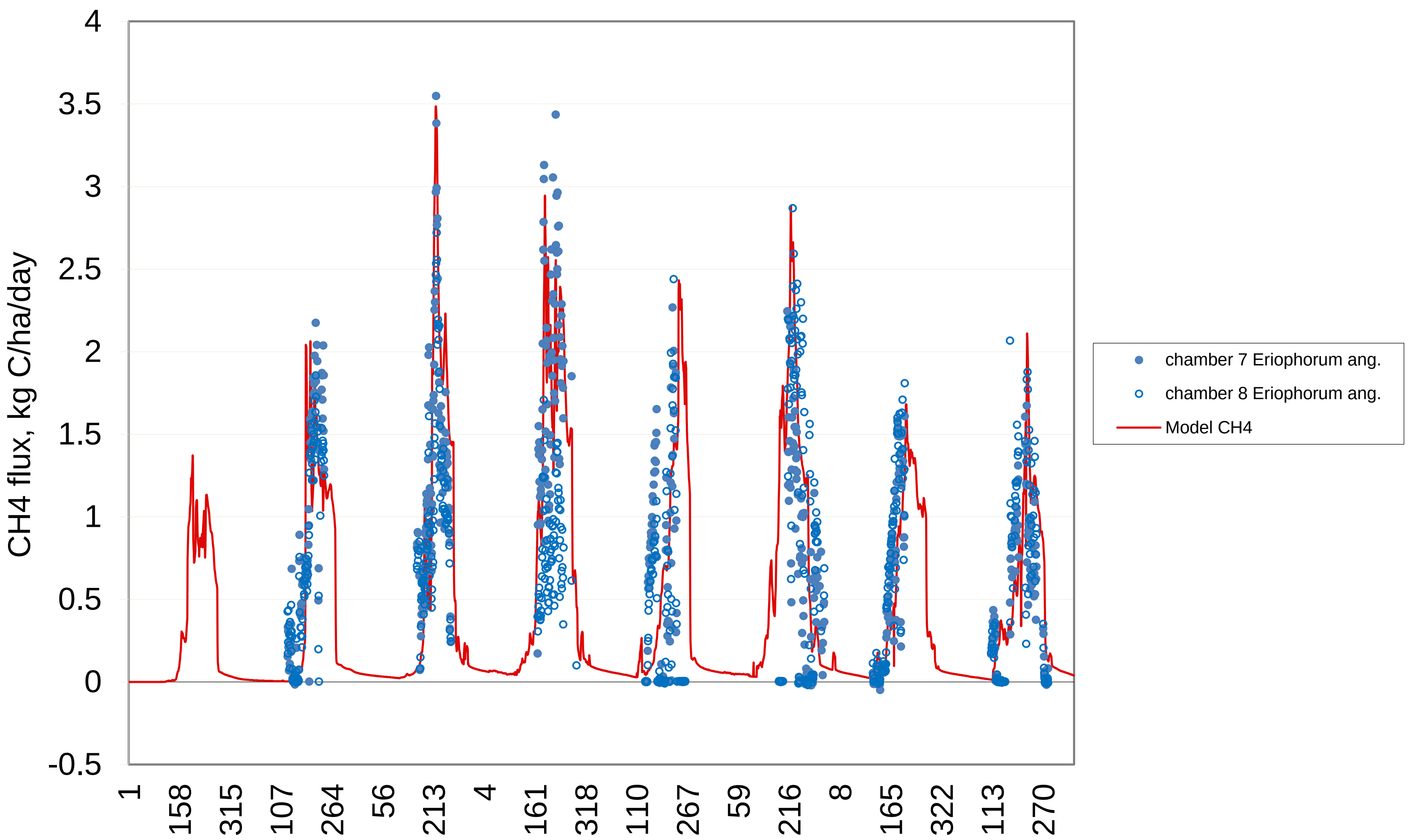
Measured and modeled ecosystem CO2 (NEE) fluxes from sedge plot at Stordalen, Sweden in 2004



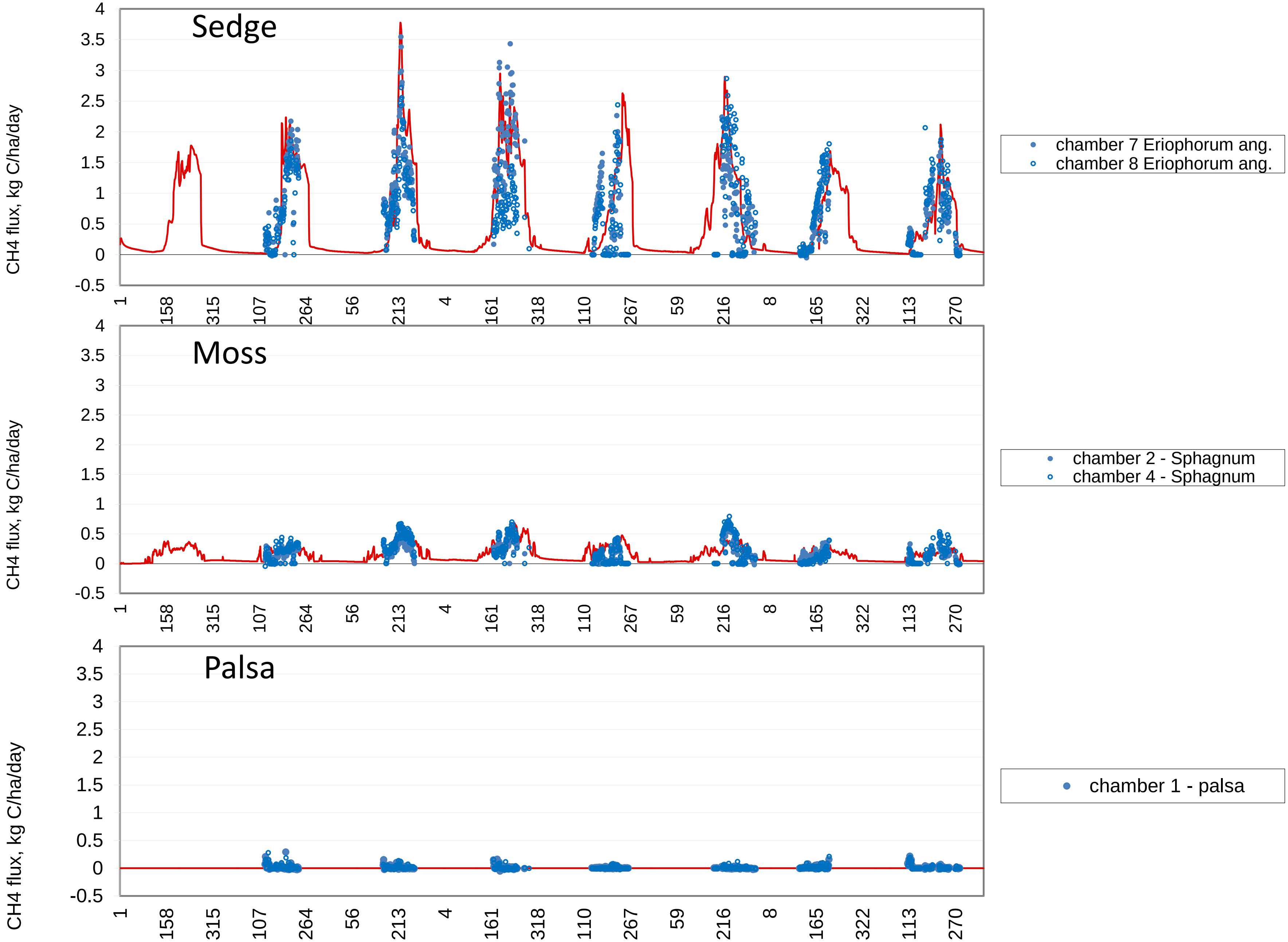
Measured and modeled CO2 fluxes from wetland at Stordalen, Sweden in 2002-2009



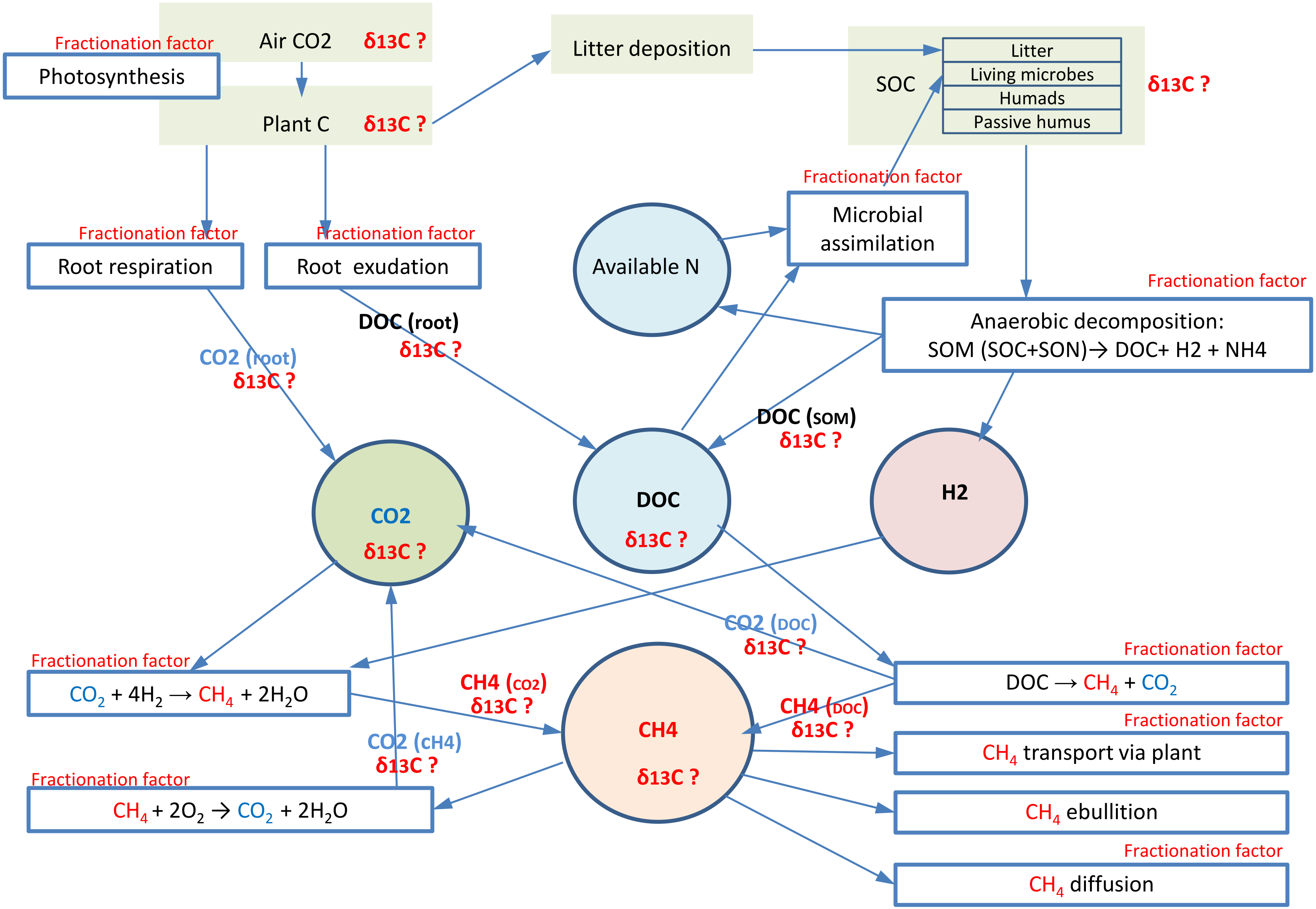
Measured and modeled CH4 fluxes from sedge-dominated plot at Stordalen, Sweden in 2002-2009



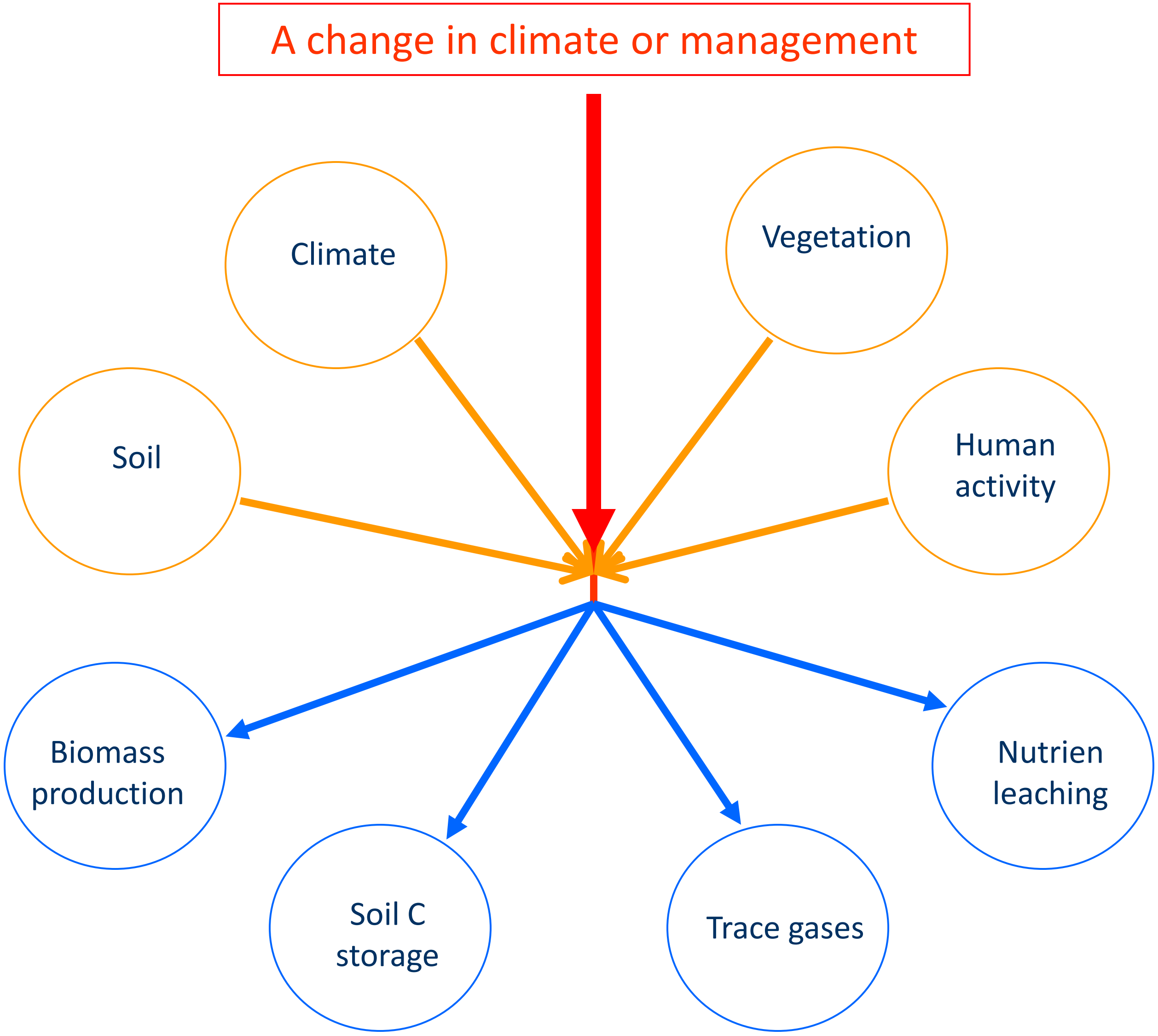
Measured and modeled CH4 fluxes from wetland at Stordalen, Sweden in 2002-2009



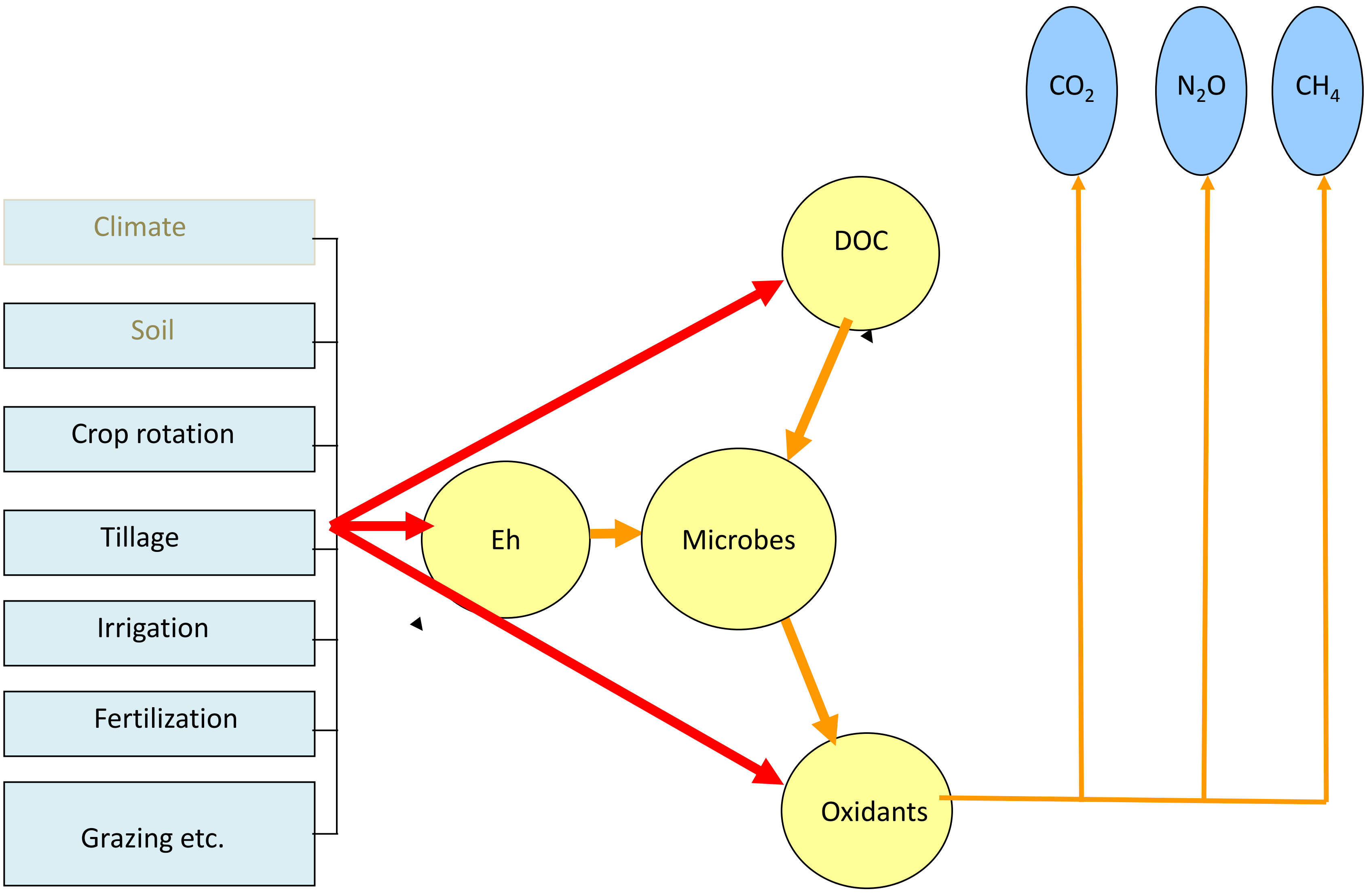
Add δ13C into DNDC's Anaerobic Processes



A Complex System



Microbes play a central role in GHG production



Mitigating N_2O by altering soil redox potential dynamics

- Altering soil compaction;
- Changing soil texture;
- Converting cultivated organic soils into wetland;
- Reducing frequency of flooding and drainage cycles in soils.

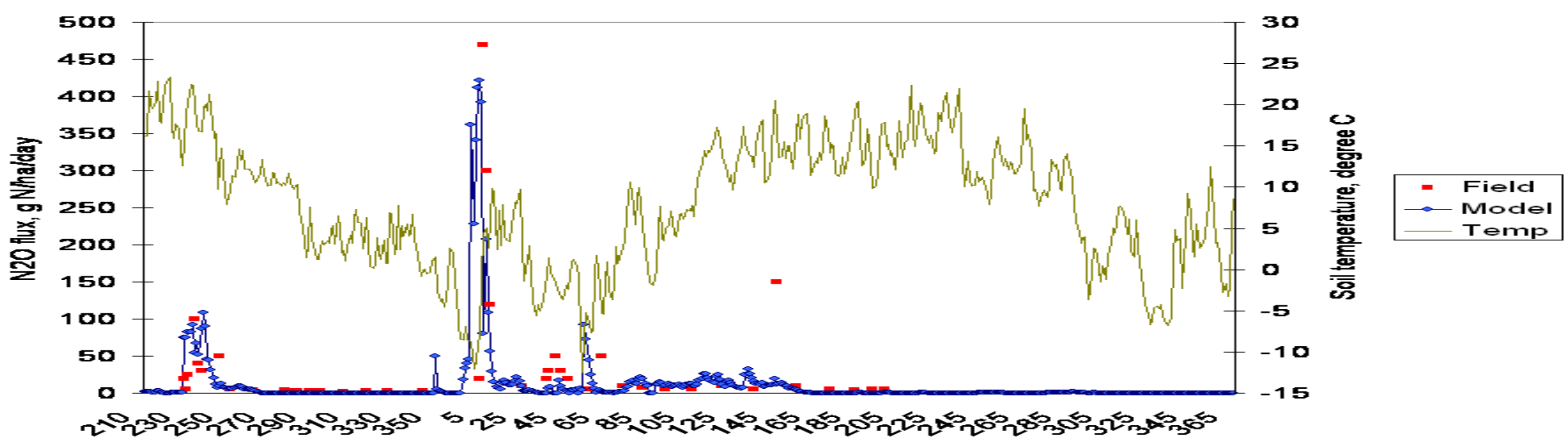
Mitigating N_2O by changing soil DOC

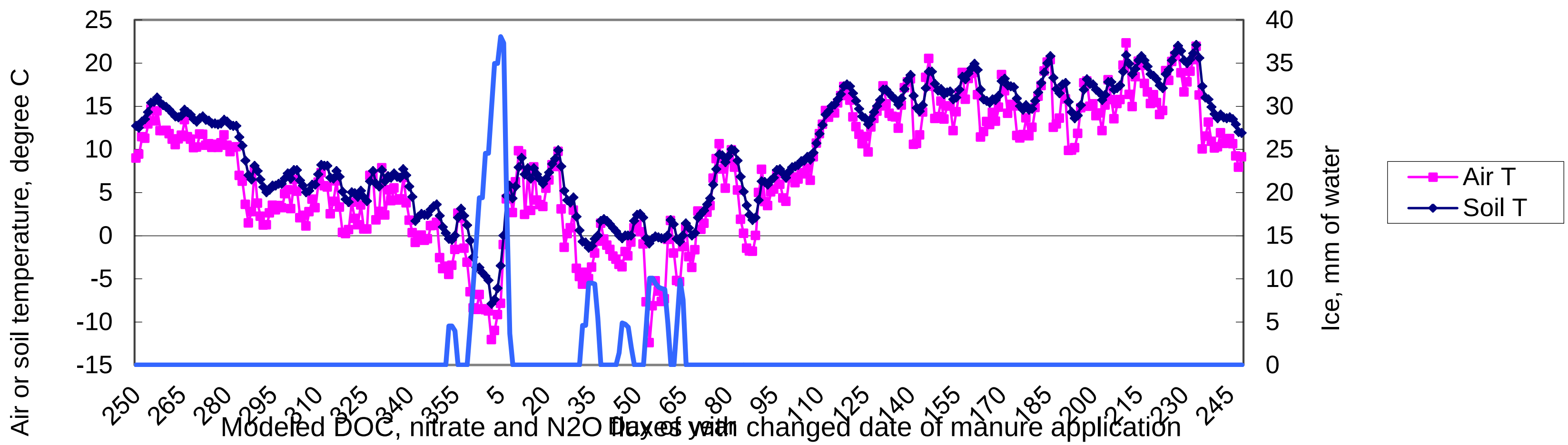
- Reduce organic matter (litter or manure) incorporation in soils.
- Decrease quality of organic matter input.
- Convert cultivated organic soils into wetland.

Mitigating N2O by reducing soil available N

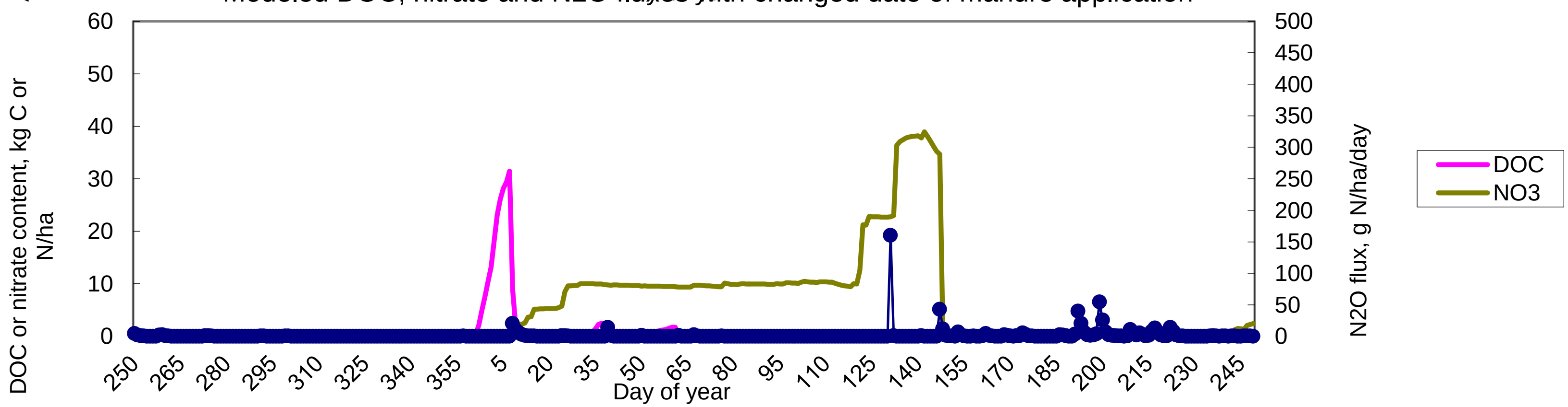
- Optimizing N fertilizer application rate.
- Applying nitrification or urease inhibitors.
- Scheduling timing of fertilizer application or release.
- Rotating with cover crop to reduce N in soil.
- Using fertigation.
- Converting organic upland to wetland.
- Changing tillage intensity.
- Using composted or digested manure.

Observed and Modeled N2O fluxes from a crop field in Germany, 1992-1993





Modeled DOC, nitrate and N2O fluxes with changed date of manure application



Discussions

GHG production results from the survival of soil microbes by consuming **energy source** and **electron acceptors** under certain **redox potential** conditions.

Altering any of the three controlling factors will reduce or eliminate GHG emissions.

Biogeochemical models are a powerful tool to evaluate alternative management practices.