Representing microbial activity in a soil decomposition model

Elin Ristorp Aas[1], Terje Koren Berntsen[1], Alexander Eiler[2] , Helge Hellevang[1]
[1]Department of Geosciences, University of Oslo
[2]Department of Biosciences, University of Oslo

UiO : Department of Geosciences
University of Oslo

Centre for Biogeochemistry in the Anthropocene

Contact:
Elin Ristorp Aas, Ph.D research fellow,
ecaas@geo.uio.no

Modelling motivation:
The exchange of carbon between the terrestrial system and the atmosphere represent a large uncertainty in Earth System Models.
In recent years, advancements in both measurement techniques and modelling has opened up possibilities for representing soil microbial activity explicitly in process based land models.
This novel approach can reduce uncertainties, and help us better understand carbon climate feedbacks between land and atmosphere.

"Real world" motivation:
Climate change cause vegetation changes in Boreal and Arctic areas. The treeline migrates upwards, and heathlands are replaced with shrubs.
The aboveground vegetation and the microbial communities below are closely connected. Therefore, knowledge about their interactions can tell us more about the consequences of these vegetation changes, especially for the role of the terrestrial system as a carbon storage.

GOAL:

- Develop a process based module that represent the carbon fluxes and pools during soil decomposition, from aboveground litter to soil organic matter (SOM).
- Eventually this kind of model can be coupled to a dynamic vegetation model, to make a consistent vegetation-soil system

UiO : Department of Geosciences
University of Oslo
Centre for Biogeochemistry in the Anthropocene

Contact:
Elin Ristorp Aas, Ph.D research fellow,
ecaas@geo.uio.no

Model Description Intro:

Wieder et al. (2014) introduced the MIMICS model, which is one of several decomposition models that represents soil microbes explicitly (Sulman et al. 2018). We used MIMICS as a starting point to create a vertically resolved soil decomposition model that explicitly represent the activity of **saprotrophs** and **mycorrhizal fungi.**

Why?

Saprotrophs gets their energy from decomposing dead material like plant litter. In the decomposition process they both build biomass carbon, and respire carbon back to the atmosphere.

We find both bacterial and fungal saprotrophs in soil, and some studies show that their decomposition rates and reactions to stress etc. are different.

We therefore decided to have two carbon pools representing saprotrophic bacteria and saprotrophic fungi, respectively.

Why?

Mycorrhizal plants and fungi live together in symbiosis. In short, plants get nutrients from the fungi, while the fungi gets carbon in return.

The different main types of mycorrhiza (ecto, ericoid and arbuscular) are associated with different plants. It is therefore interesting to study how these relationships affect the carbon dynamics when the vegetation changes.

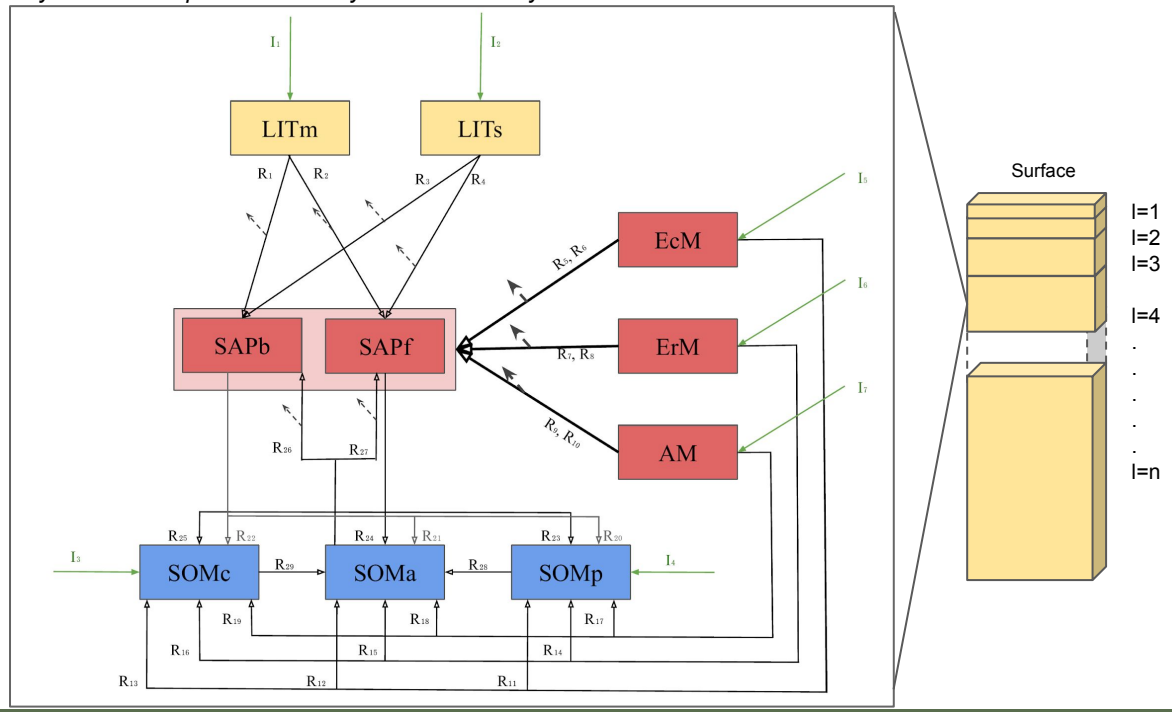
In Arctic and Boreal areas, all the three types of mycorrhiza can be important, and we therefore included one carbon pool for each of the main types: Ecto-, ericoid and arbuscular mycorrhiza.

UiO : Department of Geosciences
University of Oslo
Centre for Biogeochemistry in the Anthropocene

Contact:
Elin Ristorp Aas, Ph.D research fellow,
ecaas@geo.uio.no

Model Description:

Sketch of the model; *Left: C pools as boxes, and C fluxes as arrows. The equations corresponding to the numbered fluxes are given in the end of the presentation. LITm and LITs is metabolic and structural litter, respectively. SAPb and SAPf is carbon in saprotrophic bacteria and fungi, respectively. EcM, ErM and AM is carbon in ecto-, ericoid and arbuscular mycorrhiza. SOMc and SOMp are chemically and physically protected carbon in SOM, while SOMa are the available SOM carbon. Stitched arrows indicate heterotrophic respiration (HR). The Carbon Use Efficiency (CUE) determines how much of the total flux that reach the receiving pool, while a fraction (1-CUE) leaves the system as HR. The green arrows indicate carbon input from vegetation. Right: The system described above is simulated for each user defined layer. The transport between layers are driven by diffusion.*



Key points:

- Saprotrophic decomposition of litter, dead mycorrhiza and available SOM is represented by temperature dependent Michaelis Menten kinetics, and scaled by a moisture function.
- Carbon input to litter and SOM pools comes from aboveground sources. Input to mycorrhizal pools comes from roots.
- The rate of carbon returned to the atmosphere is determined by the Carbon Use Efficiency (CUE) of the microbes.
- The vertical transport is determined by a simple diffusion equation.

UiO : Department of Geosciences
University of Oslo

Centre for Biogeochemistry in the Anthropocene

Contact:
Elin Ristorp Aas, Ph.D research fellow,
ecaas@geo.uio.no

Comparison with Observed data from Dovre study (Sørensen et al. 2018)

For initial calibration we use data from a study by Sørensen et al. (2018) conducted in the Norwegian Dovre mountains. They measured carbon content and fluxes in three different ecosystem communities, heath, meadow and shrub, and found that the meadow community stored the most carbon below ground.

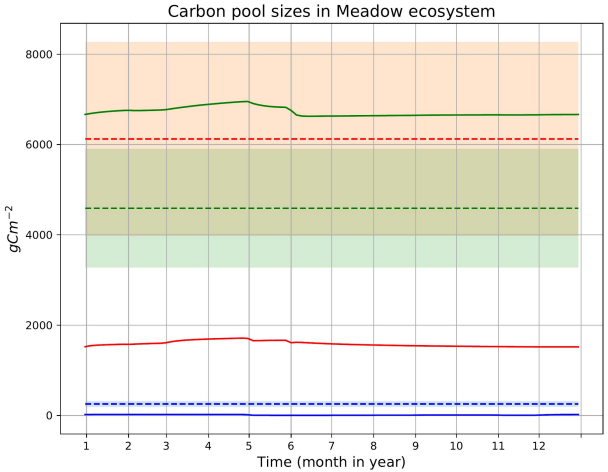
- Modelled carbon pools are combined according to the table to the right, in order to compare with the pools measured in the Dovre study.
- We assume that the input to the system is the Gross Ecosystem Productivity (GEP) from ecosystems in the Dovre data (roughly assuming that the plants produce the same amount of litter carbon as is gained through photosynthesis).
- Monthly temperature and moisture data comes from from a CLM5 simulation (NCAR data gateway).
- Shown below are carbon content in the different pools during one year (after the model has been spun up to steady state) NOTE: The values from Dovre is measured mid-growing season (june, july).

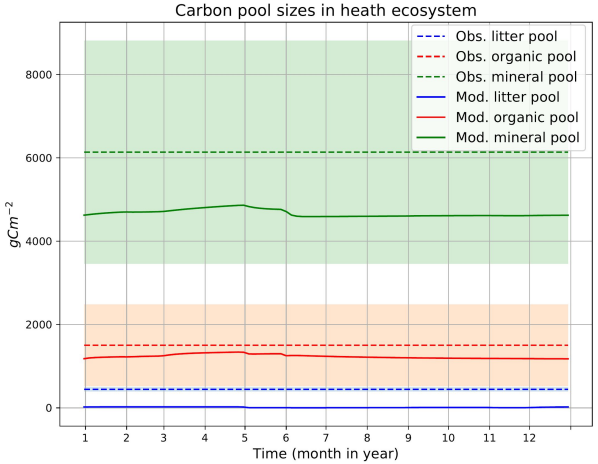
OBSERVED C POOL	MODEL CARBON POOLS
LITTER	LITm, LITs
ORGANIC	SAPb,SAPf, EcM, ErM, AM, SOMa
MINERAL	SOMp, SOMc

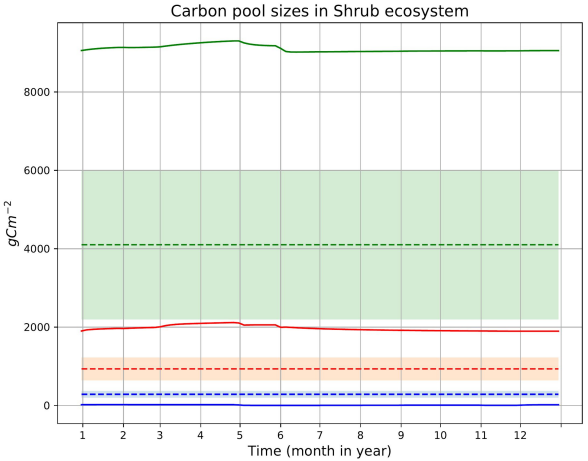
UiO : Department of Geosciences
University of Oslo
Centre for Biogeochemistry in the Anthropocene

Contact:
Elin Ristorp Aas, Ph.D research fellow,
ecaas@geo.uio.no

Comparison with Observed data from Dovre study (Sørensen et al. 2018)







Key points:

- The modelled mineral and organic pools are within the uncertainty range of observations for the Heath ecosystem simulation.
- The litter pools are underestimated in all ecosystem simulations, indicating that the decomposition rates might be too fast.
- The model fails to capture the unexpectedly high organic carbon content in the Meadow ecosystem found in the Dovre study, which might indicate that the mechanism causing this is not represented in the model.
- The large spread between the simulations show that there are still large uncertainties still present in the model, emphasizing the need for further development and improved parameterizations.

UiO : Department of Geosciences
University of Oslo

Centre for Biogeochemistry in the Anthropocene

Contact:
Elin Ristorp Aas, Ph.D research fellow,
ecaas@geo.uio.no

Final remarks and outlook:

- Comparison with the data from Dovre shows some promising results, however, many parameters are poorly constrained, and needs careful evaluation.
- We plan to include the nitrogen cycle, so that the effect of nutrient limitations can be captured.
- This work emphasizes the need for good measurement and observation studies that are compatible for use in model parameterizations. This calls for good collaborations across disciplines → Centre for Biogeochemistry in the Anthropocene

Outlook:
In the future we hope run coupled, transient simulations with a dynamical vegetation model like CLM-FATES in order to quantify the effect of soil microbes on the carbon exchange between land and atmosphere.

Contact:
Elin Ristorp Aas, Ph.D research fellow,
ecaas@geo.uio.no

“Appendix”: Equations

$$R_1 = \frac{SAPb \cdot V_{max,1} \cdot LIT_m}{K_{m,1} + LITm} \quad \text{(A.1)}$$

$$R_2 = \frac{SAPf \cdot V_{max,2} \cdot LIT_m}{K_{m,2} + LITm} \quad \text{(A.2)}$$

$$R_3 = \frac{SAPb \cdot V_{max,3} \cdot LIT_s}{K_{m,3} + LITs} \quad \text{(A.3)}$$

$$R_4 = \frac{SAPb \cdot V_{max,4} \cdot LIT_s}{K_{m,4} + LITs} \quad \text{(A.4)}$$

$$R_5 = EcM \cdot k_{EcM\_SAPb} \quad \text{(A.5)}$$

$$R_6 = EcM \cdot k_{EcM\_SAPf} \quad \text{(A.6)}$$

$$R_7 = ErM \cdot k_{ErM\_SAPb} \quad \text{(A.7)}$$

$$R_8 = ErM \cdot k_{ErM\_SAPf} \quad \text{(A.8)}$$

$$R_9 = AM \cdot k_{AM\_SAPb} \quad \text{(A.9)}$$

$$R_{10} = AM \cdot k_{AM\_SAPf} \quad \text{(A.10)}$$

$$R_{11} = EcM \cdot k_{EcM\_SOM} \cdot f_{EcM\_SOMp} \quad \text{(A.11)}$$

$$R_{12} = EcM \cdot k_{EcM\_SOM} \cdot f_{EcM\_SOMa} \quad \text{(A.12)}$$

$$R_{13} = EcM \cdot k_{EcM\_SOM} \cdot f_{EcM\_SOMc} \quad \text{(A.13)}$$

$$R_{14} = ErM \cdot k_{ErM\_SOM} \cdot f_{ErM\_SOMp} \quad \text{(A.14)}$$

$$R_{15} = ErM \cdot k_{ErM\_SOM} \cdot f_{ErM\_SOMa} \quad \text{(A.15)}$$

$$R_{16} = ErM \cdot k_{ErM\_SOM} \cdot f_{ErM\_SOMc} \quad \text{(A.16)}$$

$$R_{17} = AM \cdot k_{AM\_SOM} \cdot f_{AM\_SOMp} \quad \text{(A.17)}$$

$$R_{18} = AM \cdot k_{AM\_SOM} \cdot f_{AM\_SOMa} \quad \text{(A.18)}$$

$$R_{19} = AM \cdot k_{AM\_SOM} \cdot f_{AM\_SOMc} \quad \text{(A.19)}$$

$$R_{20} = SAPb \cdot k_{SAPb\_SOM} \cdot f_{SAPb\_SOMp} \quad \text{(A.20)}$$

$$R_{21} = SAPb \cdot k_{SAPb\_SOM} \cdot f_{SAPb\_SOMa} \quad \text{(A.21)}$$

$$R_{22} = SAPb \cdot k_{SAPb\_SOM} \cdot f_{SAPb\_SOMc} \quad \text{(A.22)}$$

$$R_{23} = SAPf \cdot k_{SAPf\_SOM} \cdot f_{SAPf\_SOMp} \quad \text{(A.23)}$$

$$R_{24} = SAPf \cdot k_{SAPf\_SOM} \cdot f_{SAPf\_SOMa} \quad \text{(A.24)}$$

$$R_{25} = SAPf \cdot k_{SAPf\_SOM} \cdot f_{SAPf\_SOMc} \quad \text{(A.25)}$$

$$R_{26} = \frac{SAPb \cdot V_{max,5} \cdot SOMa}{K_{m,5} + SOMa} \quad \text{(A.26)}$$

$$R_{27} = \frac{SAPf \cdot V_{max,6} \cdot SOMa}{K_{m,6} + SOMa} \quad \text{(A.27)}$$

$$R_{28} = SOMp \cdot k_{desorb} \quad \text{(A.28)}$$

$$R_{29} = \frac{SAPf \cdot V_{max,3} \cdot SOMc}{KO \cdot K_{m,3} + SOMc} + \frac{SAPb \cdot V_{max,4} \cdot SOMc}{KO \cdot K_{m,4} + SOMc} \quad \text{(A.29)}$$