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With funding from the:
Federal Ministry of Research, Technology and Space
CDRterra
PyMiCCS

Carbon dioxide removal through biochar and enhanced weathering: towards a scalable process-based modelling approach

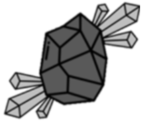
Supervisors Prof. Dr. Philipp Porada
Co-supervisor Prof. Dr. Christian Beer

Pyrogenic carbon and carbonating minerals (PyMiCCS) for enhanced plant growth and carbon capture and storage

stable organic carbon as biochar from pyrolysis of biomass

stable inorganic carbon as alkalinity from weathering rocks

Fresh silicate rock + CO_2 ⇩ + H_2O ⇨ clay + HCO_3^- + cations



PyMiCCS as combination of two high potential methods

Source: Maria Ansari, 2nd CDRterra General Assembly, PyMiCCS

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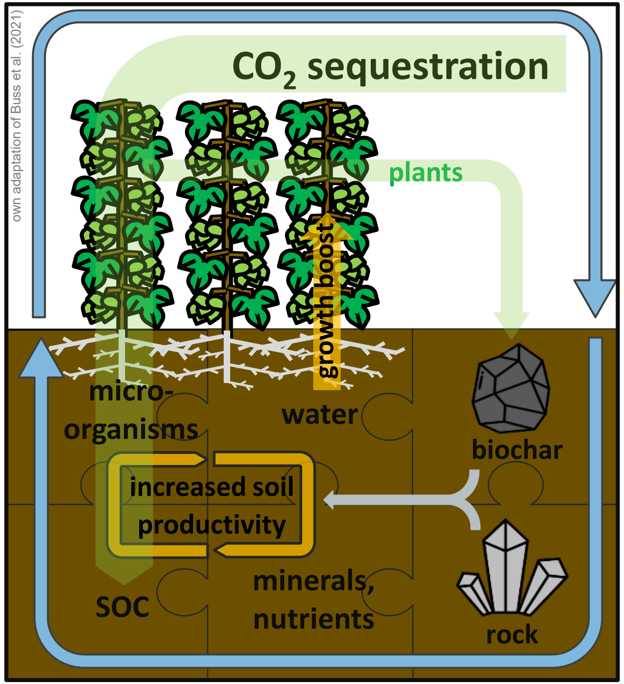
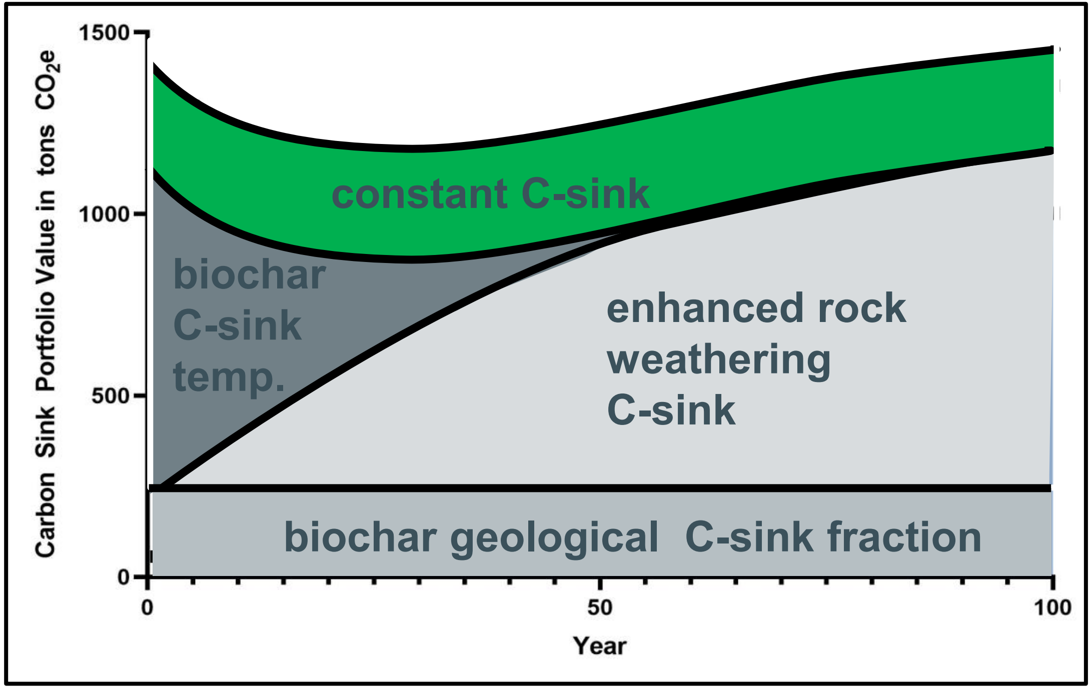
PyMiCCS as improvement of soil properties



PyMiCCS as a CDR method



Source: ad. of 2nd CDRterra General Assembly, PyMiCCS presentation
ad. of Hagemann (2024), German Biochar Forum presentation

Main objectives:

- How does the soil-vegetation system respond to PyMiCCS applications?
- How do these responses control long-term carbon sequestration efficiency in amended soils?

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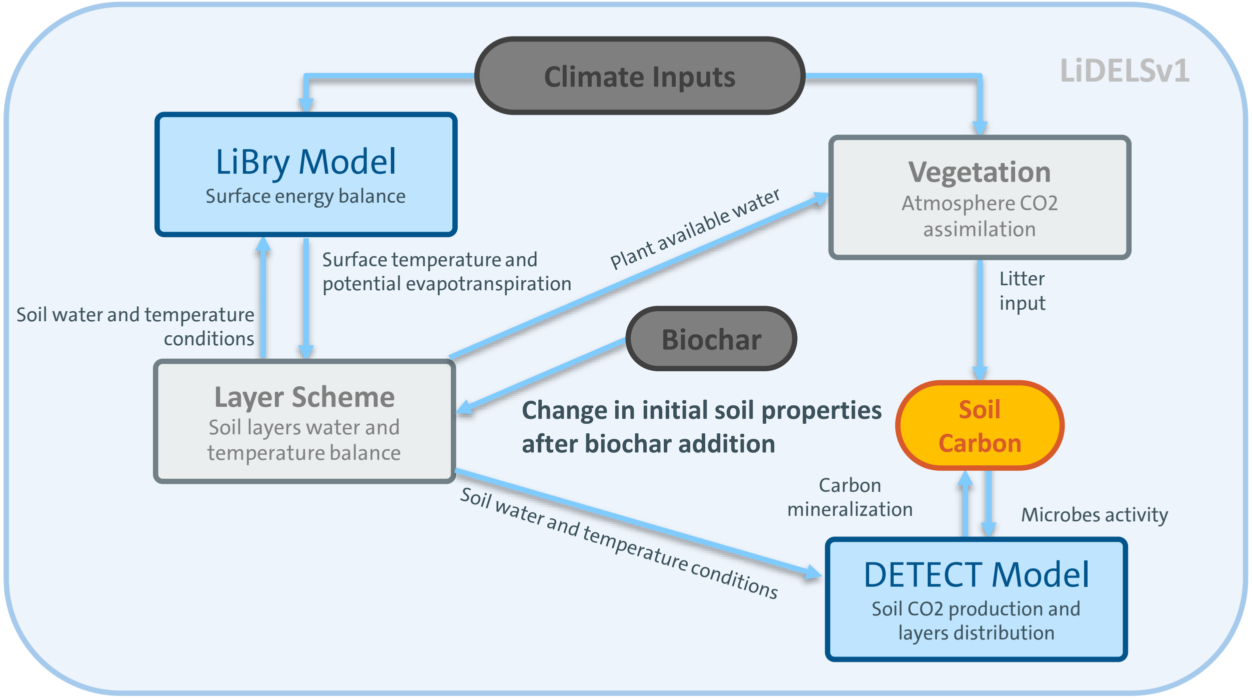
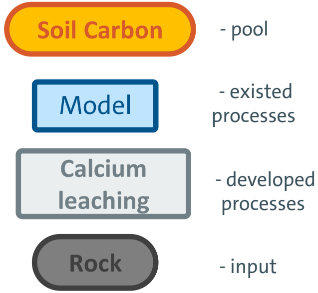
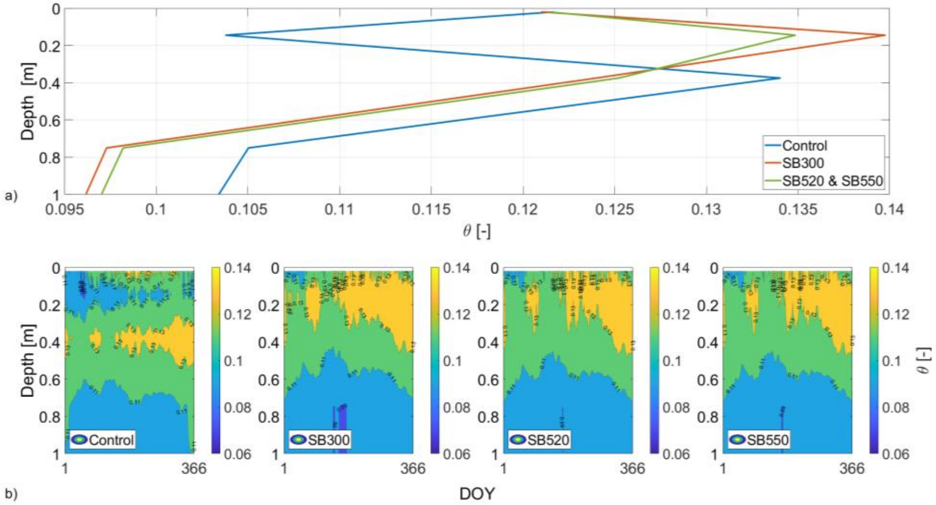
LiBry-DETECT Layer Scheme version 1 (LiDELS v1)



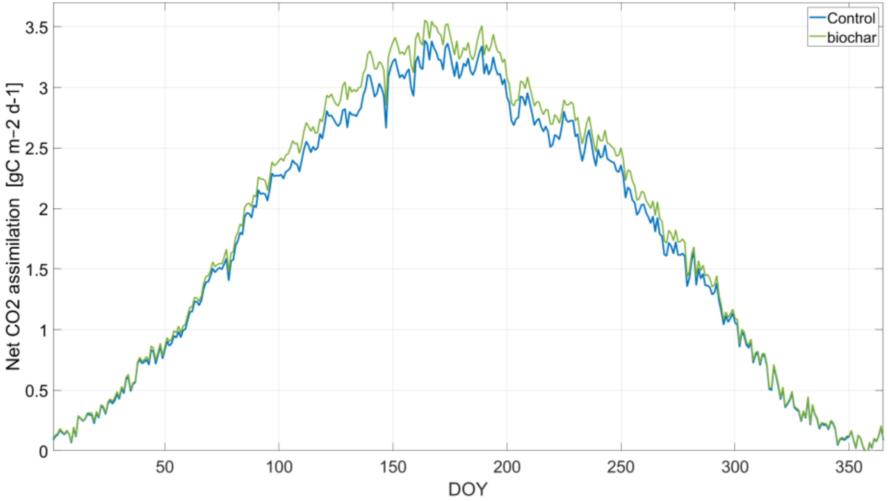


[1] Maslouski, M., Porada, P. (2024) “LiBry-DETECT Layer Scheme version 1 (LiDELSv1) model.” *Zenodo*. doi.org/10.5281/zenodo.14849558

1st publication: biochar addition to sandy soil for Hamburg climate data



(a) mean soil water content for control soil and three biochar treatments



(b) mean annual CO2 assimilation for control soil and biochar treatments

[2] Maslouski, M., Eschenbach, A., Beer, C., Thomsen, S., Porada, P. (2025) "Soil and vegetation responses to biochar application in terms of its feedback on carbon sequestration under different environmental conditions – LiDELS model overview." *Environ. Res. Lett.* 20, 044020. doi.org/10.1088/1748-9326/adbfa6

1st publication: biochar addition to sandy soil for Hamburg climate data

Medium term biochar addition to sandy soil:

Biochar improved water retention

↓

higher CO_2 assimilation by plants (NPP)

↓

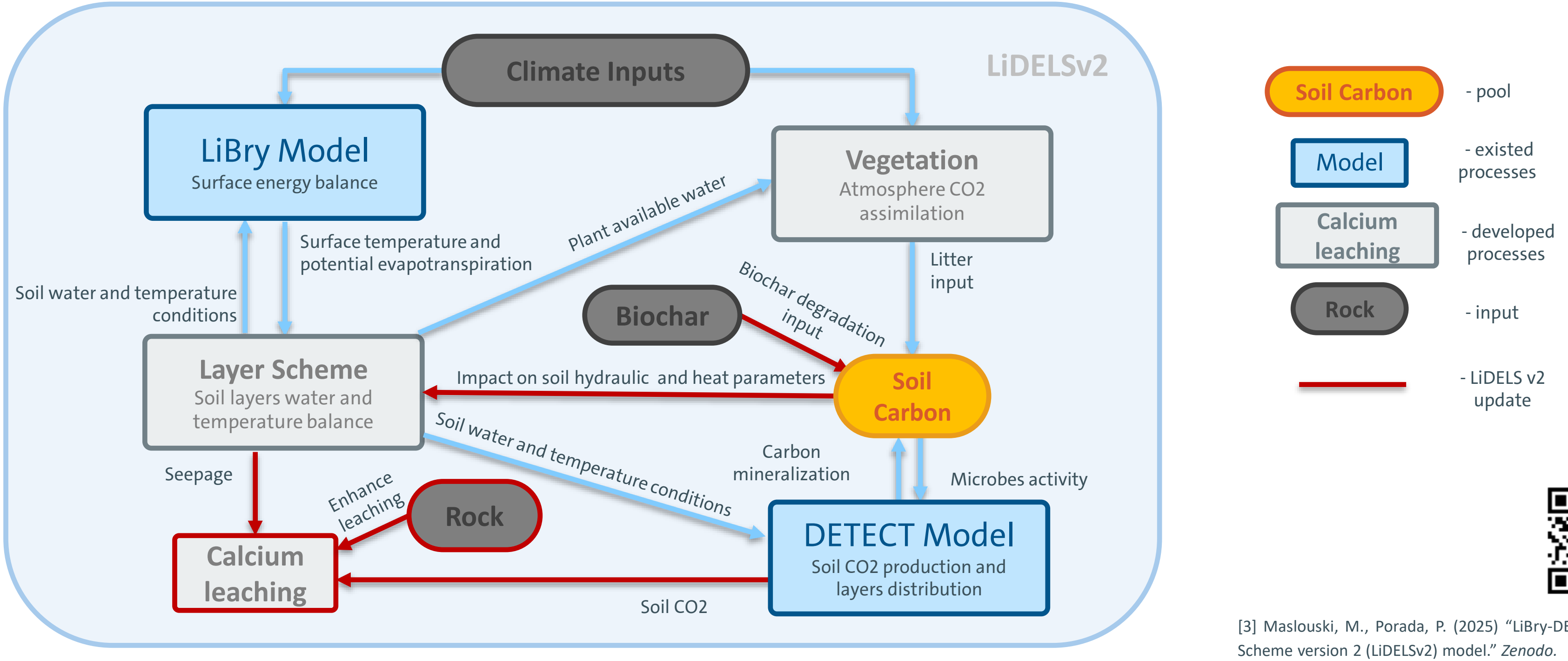
more plant-derived carbon inputs to soil, with only minor increases in soil respiration

↓

net soil organic carbon (SOC) gain

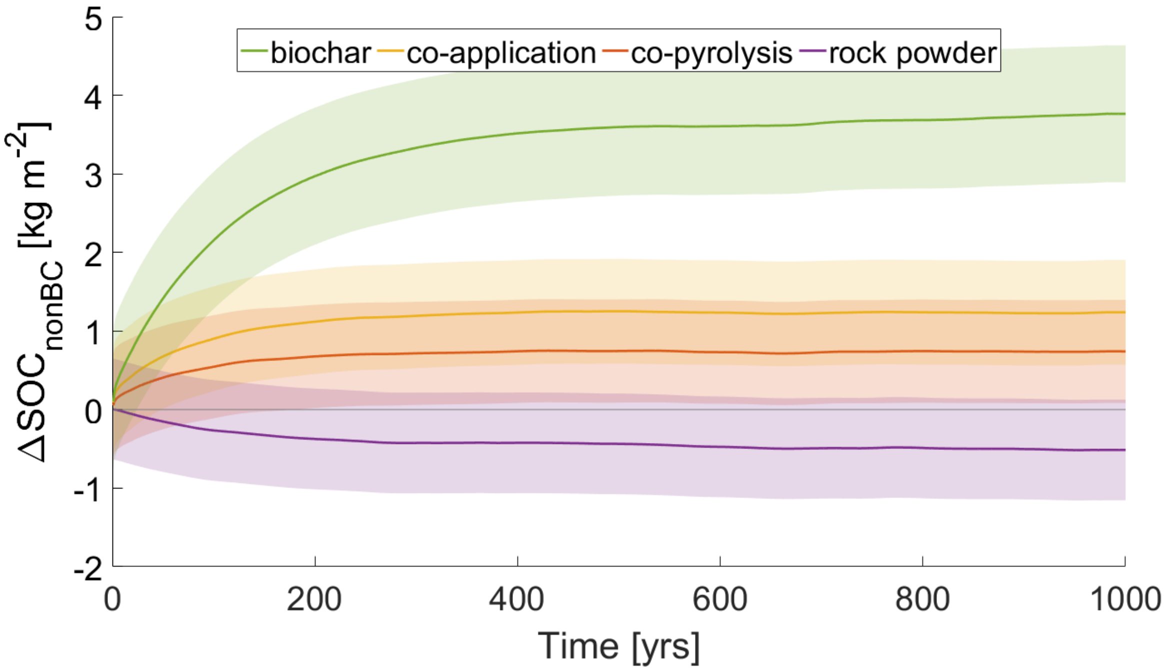
[2] Maslouski, M., Eschenbach, A., Beer, C., Thomsen, S., Porada, P. (2025) “Soil and vegetation responses to biochar application in terms of its feedback on carbon sequestration under different environmental conditions – LiDELS model overview.” *Environ. Res. Lett.* 20, 044020. doi.org/10.1088/1748-9326/adbfa6

LiDELS version 2 (LiDELS v2)



[3] Maslouski, M., Porada, P. (2025) “LiBry-DETECT Layer Scheme version 2 (LiDELSv2) model.” *Zenodo*. doi.org/10.5281/zenodo.16151579

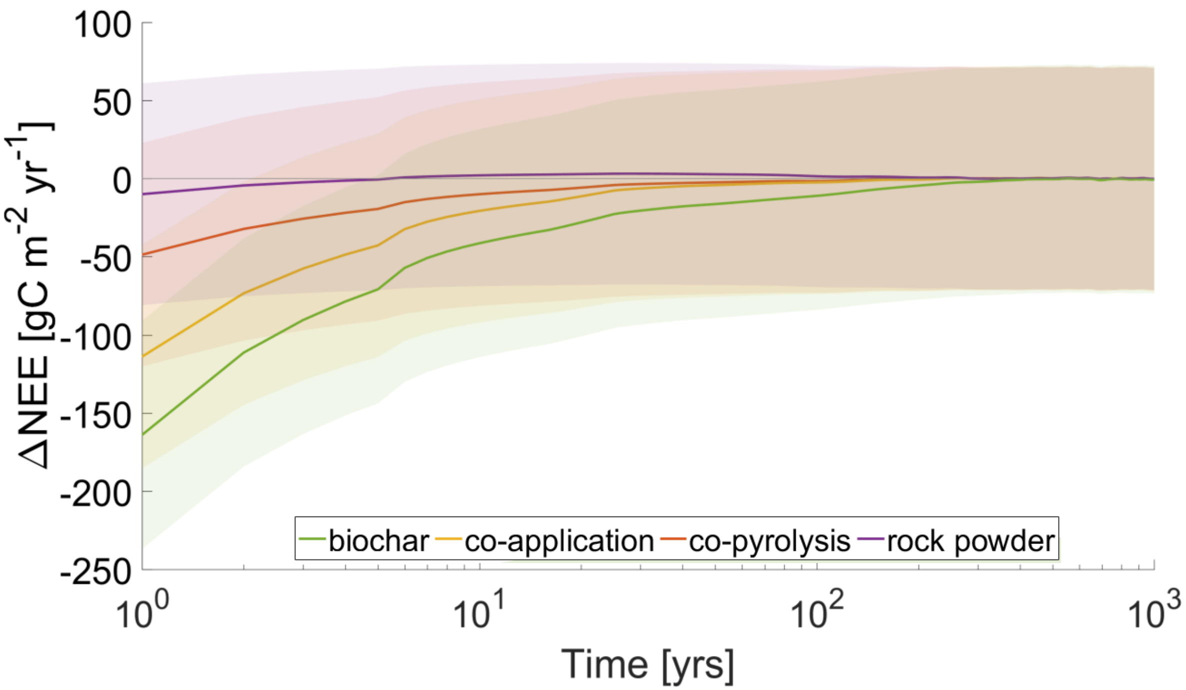
2nd publication: PyMiCCS long-term CDR potential



Change in mean **non-biochar soil organic carbon** relative to the modeled Control treatment (ΔSOC_{nonBC}) in soil column.

[4] Maslouski, M., Seedtke, M., Hamburger, S. E., Meyer zu Drewer, J., Hagemann, N., Eschenbach, A., Beer, C., Becker, J. N., Kammann, C. I., Vorrath, M.-E., Porada, P. (2025) "Long-term carbon dioxide removal potential from the application of wood biochar and basanite rock powder in sandy soil using the LiDELSv2 process-based modeling approach." *Environ. Res. Lett*. 20 124032 doi: 10.1088/1748-9326/ae21f6.

2nd publication: PyMiCCS long-term CDR potential



Change in **net ecosystem exchange** over time compared to the modeled Control soil column (ΔNEE).

[4] Maslouski, M., Seedtke, M., Hamburger, S. E., Meyer zu Drewer, J., Hagemann, N., Eschenbach, A., Beer, C., Becker, J. N., Kammann, C. I., Vorrath, M.-E., Porada, P. (2025) "Long-term carbon dioxide removal potential from the application of wood biochar and basanite rock powder in sandy soil using the LiDELSv2 process-based modeling approach." *Environ. Res. Lett*. 20 124032 doi: 10.1088/1748-9326/ae21f6.

2nd publication: PyMiCCS long-term CDR potential

Under the modeled conditions:

- **Biochar alone was the dominant long-term CDR agent** in sandy soils, contributing to an increase in SOC and resulting in negative NEE over 1,000 years.
- **Rock powder application alone had no positive effect on SOC or NEE**, and its CDR potential via enhanced Ca^{2+} leaching was minimal.
- **Co-application and co-pyrolysis improved SOC stocks but were less effective than biochar alone**, suggesting that combining biochar with rock powder may reduce its long-term CDR performance.

[4] Maslouski, M., Seedtke, M., Hamburger, S. E., Meyer zu Drewer, J., Hagemann, N., Eschenbach, A., Beer, C., Becker, J. N., Kammann, C. I., Vorrath, M.-E., Porada, P. (2025) "Long-term carbon dioxide removal potential from the application of wood biochar and basanite rock powder in sandy soil using the LiDELSv2 process-based modeling approach." *Environ. Res. Lett*. 20 124032 doi: 10.1088/1748-9326/ae21f6.

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Conclusion & Outlook

The complexity of PyMiCCS:

- **Non-additive effects:** combined application of biochar and rock powder is not simply the sum of its parts; internal feedbacks can either accelerate or dampen sequestration.

- **Case study perspective:** for Hamburg-type soils, for amendments introduced changes in porosity, K_{sat}, SWRC; no nutrient cycling, simplified weathering (only Ca^{2+}) and no non-CO_2 GHGs

- **The power of LiDELS:** it is one of the few models to successfully couple soil physics (hydrology/thermal) with biological carbon cycles (NPP/microbial respiration) and chemical weathering.

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Conclusion & Outlook

The path forward: scaling and reliability

- **Spatial upscaling:** moving from 1D site-specific simulations to regional and global spatial mapping
- **Missing components:** nutrient cycles and geochemistry

Final Statement:

Sustainable climate mitigation requires more than just adding carbon or rock to the soil. It requires a deep, mechanistic understanding of the soil-vegetation-atmosphere continuum.