U.S. DEPARTMENT OF ENERGY | Office of Science

BIOGEOCHEMICAL TRANSPORT AND REACTION MODULE (BETR): ROBUST LAND BIOGEO-CHEMISTRY MODEL DEVELOPMENT IN E3SM

The Biogeochemical Transport and Reactions (BeTR) module is a reactive transport software package designed to help the scientific community improve regional and global biogeochemistry projections within earth system models (ESMs).

Developed by scientists at Lawrence Berkeley National Laboratory (Tang et al. 2013; Tang and Riley 2018; Riley et al. 2020), BeTR supports fast, robust, and flexible modeling of soil biogeochemistry. It is designed to improve understanding of how soil biogeochemistry responds to and affects changes in regional and global climate systems.

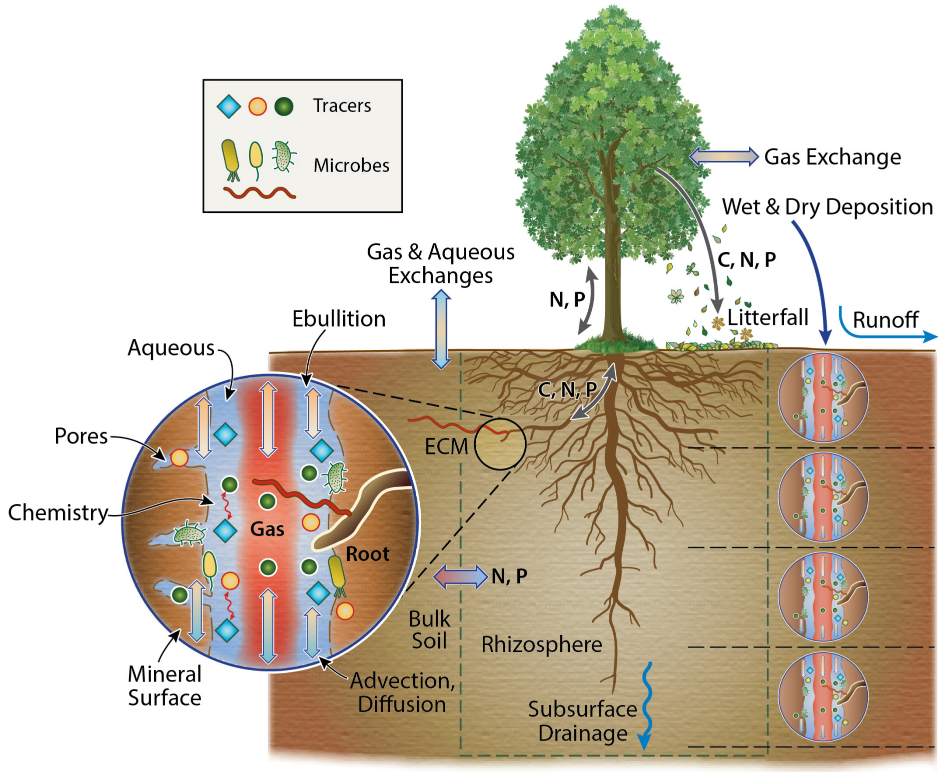
REDUCING BIOGEOCHEMICAL PROCESS UNCERTAINTY

Below-ground processes strongly affect terrestrial carbon exchanges with the atmosphere, and representation of these processes is over-simplified in some models. BeTR uses a mechanistic approach that represents vertically resolved reactions and transport in soil that are important for carbon and nutrient cycling.

Land models integrated into ESMs contribute to uncertainties in climate projections, a major part of which can be attributed to soil biogeochemical (BGC) processes. Previous soil modules did not support the active representation of transport and reaction of various chemical species and biological agents. As a result, structural uncertainty in model representations was difficult to characterize within a single ESM.

BeTR addresses this technical gap and reduces uncertainty. Its modular design integrates solutions for many common BGC processes, such as multiphase transport and reaction, tracer labeling, and multiple competitor interactions using well-tested numerical solvers and theories.

BeTR allows earth system modelers to focus on exploring scientific questions and frees them from the often-challenging design and integration of numerical solution strategies to link them with a range of soil BGC processes. This reactive transport framework enables structural uncertainty quantification without confounding factors, such as dissimilar model configurations and driving data, which have made past land modules difficult to interpret.



A schematic of the BeTR reaction module integrated into the E3SM Land Model (ELMv1; Tang and Riley 2018).

PROJECTING LAND ECOSYSTEM RESPONSE

Modeling land biogeochemistry—the transport, interactions, and biotic and abiotic transformations of chemical species in dissolved, gaseous, sorbed, and aggregate phases—is an important element of the credible projection of future climate and understanding of how land ecosystems will respond to and interact with future climate change.

Get BeTR

Code and documentation: https://github.com/BeTR-biogeochemistry-modeling/sbetr

Some models, however, struggle to integrate the myriad of processes to deliver robust projections consistently. The challenges include:

- Resolving the multiphase nature of ecosystem biogeochemistry;
- Selecting from among the wide range of mathematical formulations for each of the biogeochemical processes; and
- Integrating new, critical processes identified from empirical measurements.

BeTR resolves these challenges systematically by employing numerical solvers and adopting a modular design that enables modelers to focus on the processes themselves rather than technical details of how these processes should be integrated.

FLEXIBILITY FOR COUPLED ANALYSIS

The concept of BeTR is to streamline detailed coupled analyses in ESMs. Users enter BGC data into the BeTR platform and then directly connect with an ESM or perform standalone simulations.

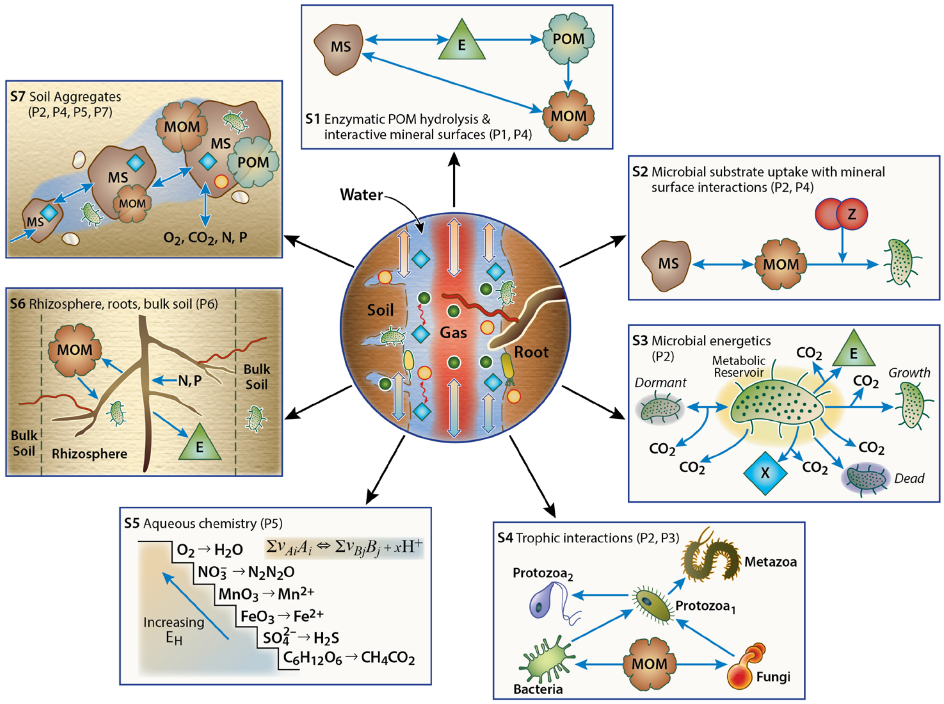
To address complex biogeochemistry research challenges, BeTR is designed for flexibility to meet the needs of each model simulation. For example, key algorithms can be swapped with other modules and subroutines. And based on output needs, BeTR allows users to switch functions on and off.

BeTR allows users to easily incorporate new processes based on the provided model templates that have been well tested across platforms. BeTR implementation allows:

- Governing equations solved using a process splitting approach;
- Implicit solver for dual-phase diffusion;
- Aqueous fluid advection using a semi-Lagrangian scheme;
- Ebullition using a pressure adjustment scheme; and
- Tracer transport by groups.

E3SM INTEGRATION

While BeTR can be used with most current ESMs, it is optimized to couple with the Energy Exascale Earth System Model (E3SM, e3sm.org), the Department of Energy's state-of-the-science earth system model development and simulation project. When paired with E3SM, BeTR can accelerate soil BGC model development and evaluation, improving ESM projections.



A schematic of seven important classes of processes that affect soil BGC that can be represented within BeTR: (*S1*) litter input and polymeric soil organic matter degradation; (*S2*) microbial physiology, microbial population dynamics, and macronutrient controls; (*S3*) trophic interactions; (*S4*) mineral-organic interactions; (*S5*) soil redox and pH chemistry; (*S6*) rhizosphere-bulk soil interactions; and (*S7*) soil structure dynamics (Riley et al. 2020).

SUPPORT

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REFERENCES

Tang, JY and WJ Riley. 2018. "Predicted Land Carbon Dynamics Are Strongly Dependent on the Numerical Coupling of Nitrogen Mobilizing and Immobilizing Processes: A Demonstration with the E3SM Land Model," *Earth Interact*, 10.1175/EI-D-17-0023.1.

Tang, JY, WJ Riley, CD Koven, and ZM Subin. 2013. "CLM4-BeTR, a generic biogeochemical transport and reaction module for CLM4: model development, evaluation, and application," *Geoscientific Model Development*, 10.5194/Gmd-6-127-2013.

Riley, WJ, C Sierra, JY Tang, NJ Bouskill, Q Zhu, and R Abramoff. 2020. "Next generation soil biogeochemistry model representations: A proposed community open source model farm (BeTR-S), accepted Multi-scale Biogeochemical Processes in Soil Ecosystems: Critical Reactions and Resilience to Climate Changes," edited by Y Yang, M Keiluweit, N Senesi and B Xing.