Modelling Global Distribution of Nitrogen Fixation by Heterotrophic Bacteria in Sinking Marine Particles

Overview

Nitrogen fixation is a crucial process in the marine nitrogen cycle, converting atmospheric nitrogen (N_2) into biologically available forms that support ocean productivity and influence global biogeochemical cycles. Traditionally, it has been believed that N_2 fixation is predominantly carried out by cyanobacteria. However, recent discoveries have identified the presence of nitrogen-fixing genes in heterotrophic bacteria across nearly all regions of the global ocean. Despite this finding, the contribution of these heterotrophic bacterial N_2 fixers to global nitrogen fixation remains largely unknown.

Project Description

Our project aims to develop a comprehensive mathematical model to simulate the global distribution of nitrogen (N_2) fixation by heterotrophic bacteria residing within sinking marine particles. These particles, primarily composed of a variety of organic matter, including dead or dying animals and phytoplankton, protists, fecal matter, sand, and other inorganic dust, serve as microhabitats for bacteria, which play a critical role in oceanic nitrogen cycles. By utilizing the computational resources at the Deutsches Klimarechenzentrum (DKRZ), we aim to conduct high-resolution simulations that provide the estimation of N_2 fixation by heterotrophic bacteria on a global scale.

The core of our model focuses on the metabolic activities of bacterial cells within sinking marine particles. These activities are influenced by several factors:

1. **Degradation of Organic Matter and resource uptake:** Bacteria grow inside sinking particle and release ectoenzymes to degrade polysaccharides into glucose and polypeptides into amino acids. These smaller molecules are then ingested to extract essential carbon and nitrogen to facilitate bacterial growth. All these processea are temperature dependent.

2. **Respiration and N_2 Fixation:** Bacteria maintain respiration through electron acceptors and regulate N_2 fixation to supplement nitrogen intake, optimizing their growth.

3. **Elemental Diffusion:** There is a diffusion of elements between the marine particles and the surrounding seawater, a process influenced by temperature.

The model further categorizes marine particles into different size classes, each with distinct sinking velocities. As particles descend through the water column, they encounter varying vertical gradients of oxygen (O_2), nitrate (NO_3), and temperature. By integrating these gradients into our model, we aim to capture the dynamic interaction between sinking particles and their ambient environment. Finally, the model will be executed on the global ocean using a grid resolution of 1 degree by 1 degree.

Computational Goals

1. **Vertical Distribution of N_2 Fixation:** We will calculate the vertical distribution of N_2 fixation within each size class of particles across different spatial grid points.

2. **Depth-Integrated N_2 Fixation:** The model will determine the distribution of depth-integrated N_2 fixation by particle-associated heterotrophic bacteria on a global scale.

3. **Total Fixed N_2:** We will estimate the total amount of fixed N_2 contributed by these bacteria globally.

Computational Requirements

Given the complexity and scale of this project, we require the advanced computational facilities provided by DKRZ. Our simulations will leverage high-performance computing to:

- Run detailed, temperature-dependent biogeochemical models.
- Process large datasets representing vertical gradients of O_2, NO_3, and temperature across the global ocean.
- Conduct extensive sensitivity analyses to refine and validate our model.

Expected Outcomes

The outcomes of this project will significantly enhance our understanding of the role of heterotrophic bacteria in marine nitrogen cycles. Specifically, our findings will provide insights into the contribution of bacterial N_2 fixation within sinking particles, a process crucial for marine nutrient dynamics. The model outputs will also inform future oceanographic studies and contribute to more accurate global biogeochemical models.

We anticipate that the results from our simulations will be of interest to the broader scientific community, particularly those studying marine microbiology, biogeochemistry, and climate change. By utilizing the facilities at DKRZ, we aim to produce robust, high-resolution data that will advance our knowledge of oceanic nitrogen fixation and its implications for global biogeochemical cycles.