Modeling the biological carbon pump

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**Introduction**

**Context:** atmospheric CO\textsubscript{2} controls our climate, and is itself controlled by a plethora of factors. Our understanding of past, current, and future CO\textsubscript{2} levels hinges on our ability to quantify all CO\textsubscript{2} sources and sinks.

**Focus:** the biological carbon pump: biota-controlled transport of CO\textsubscript{2} from the atmosphere to the ocean deep. Near the ocean surface, plankton builds organic carbon from CO\textsubscript{2}. Part of this carbon sinks, passes a diffusion barrier, and is locked in the ocean deep.

**Aim:** to understand the global influence of the biological carbon pump. We employ mathematical models that combine geophysical, biological, and mathematical expertise. Our focus is on informed simplification: use model biological and physical processes on their relevant (small) scales, then seek well-founded parameterizations to feed global climate models.

We study the biological carbon pump in a 1D model of the marine water column, focusing on the main controls of the carbon pump:

- Marine ecosystems
- Turbulence
- Marine snow

Figure 1 illustrates the interplay of these processes.

![Image](1.jpg)

**Marine ecosystems**

Phytoplankton converts CO\textsubscript{2} to biomass. The fate of fixed organic carbon depends on many factors, as phytoplankton stands at the base of an elaborate food web (Figure 1).

**Important processes:**
- Phytoplanktonic: phytoplankton fixes CO\textsubscript{2} in the presence of light and nutrients.
- Producers: autotrophic production depends on phytoplankton.
- Detrital: feeders, herbivores, grazers consume detritus and partially transform it into the original nutrients.

**How modeled?**

The Dynamic Energy Budget theory (DEB) \cite{1} is a consistent, quantitative approach to biological modeling. We will develop a DEB-based population model that supports any relevant biological activity through quantifiable traits. Investment in traits brings benefits (typically an increase in food supply), but also costs in growth and maintenance of biomass.

We assume infinite biodiversity; every possible combination of traits can be found in the marine ecosystem. This implies continuous distributions of all traits. We propose to initialize the model in the ocean spring with uniform trait distributions and low biomass. Evolution of trait combinations then represents the rise and fall of species and functional groups.

**Turbulence**

‘Turbulence’ = unstable, variable-sized, unidirectional eddies. Produced by:
- Buoyancy: unstable gradients in density form by cooling and evaporation of surface water.
- Shear: flow velocity gradients are created by wind, waves, and tides.

Turbulence is high in autumn and winter, when storms shear and cool the surface. In summer, heating of the surface creates a stable density gradient: the water is stratified and non-turbulent.

**Effects**

Turbulence mixes everything across the water column. As such, it:
- Stimulates biological productivity by supplying nutrients.
- Reduces phytoplankton productivity by decreasing the average light intensity experienced by phytoplankton.

**How modeled?**

Many empirical models parameterize turbulence. We use the General Ocean Turbulence Model (GOTM) \cite{2}, which can simulate turbulence in a water column with a variety of models.

**Marine snow**

‘Marine snow’ = variable-sized particles mostly detritus. Larger particles form when small particles meet and stick together. Particles meet due to:
- (Turbulent) shear: differences in traveling speed cause particles to meet.
- Brine: density of small particles ‘diffuse’ towards one another.
- Differential advection: differences in sinking rates cause particles in the same column to meet.

Particle formation is partly controlled by the presence of sticky dissolved organic matter (DOM), excepted by nutrient-limited phytoplankton. Also, large particles can break down due to shear stress in environments with high turbulence.

**Effects**

Coagulation increases the average particle size, and therewith the average sinking rate. Doing so, it:
- Explores organic carbon to the deep.
- Decreases percentage of remineralization, indirectly affecting future nutrient supply.

**How modeled?**

We discretize the particle size distribution, and parameterize the processes creating and destroying particles \cite{3}.

**References**


**More info**

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For more information: http://www.bio.vu.nl/thb/personnel/members/bruggeman.html
http://wwwbio.vu.nl/jorn.bruggeman@falw.vu.nl

Notes:

- >200 size classes to describe marine snow
- >5 layers in the vertical to describe turbulence
- More sophisticated models bring complexity. A first attempt to model the top of the water column might lead to:
  - >3 trait distributions, >10 cells each, to describe biodiversity.
  - >200 size classes to describe marine snow.
  - >5 layers in the vertical to describe turbulence.