Environmental controls on N_2 fixation by *Trichodesmium* in the tropical eastern North Atlantic

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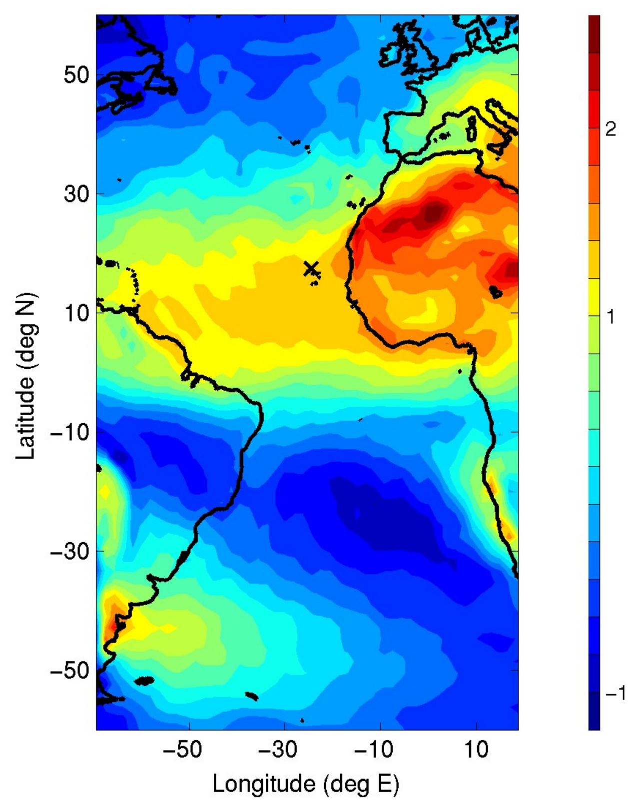
A model of nitrogen fixation at TENATSO

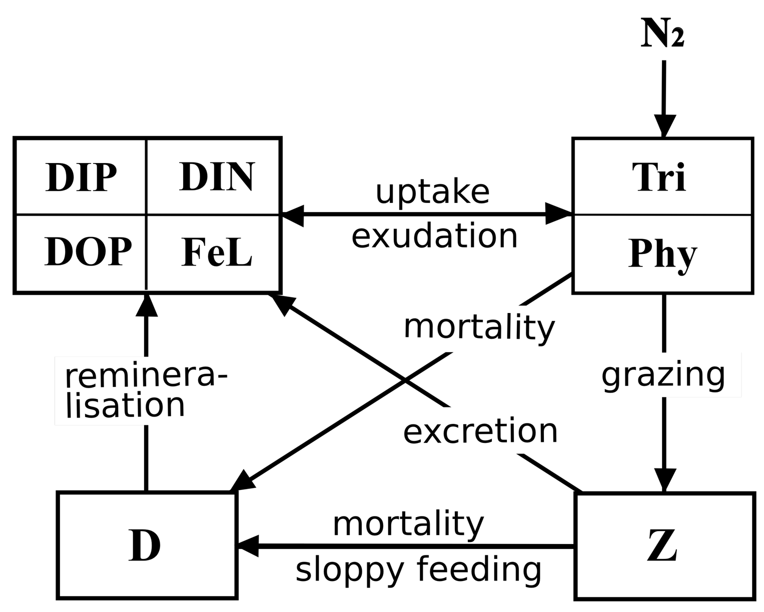
The low surface nitrate concentration and high atmospheric iron input in the tropical eastern North Atlantic provide beneficial conditions for N_2 fixation. Different abundances of diazotrophs have been observed and an Fe- and P-colimitation of N_2 fixation was reported in this ocean region. It is however unclear how different limiting factors control the temporal variability of N_2 fixation and what the role of Fe-limitation is in a region with high fluxes of dust deposition.

To study the environmental controls on N_2 fixation, a one-dimensional ecosystem model is coupled with a physical model (General Ocean Turbulence Model) for the Tropical Eastern North Atlantic Times-series Station (TENATSO), north of the Cape Verde Islands.



Logarithm of the annual mean dust deposition flux (g m^{-2} a^{-1}) from Mahowald et al. (2003). The black cross indicates the location of TENATSO (17°N, 24.5°W).

Components of the ecosystem model

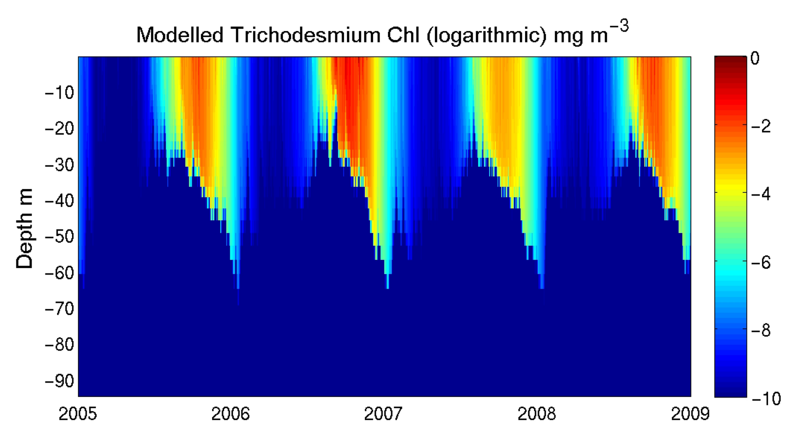


A NPZD-type ecosystem model is extended by including:

- one diazotrophic (Tri) and one non-diazotrophic (Phy) phytoplankton;
- four nutrient pools: dissolved inorganic nitrogen (DIN), bioavailable iron (FeL), dissolved inorganic (DIP) and organic phosphorus (DOP).

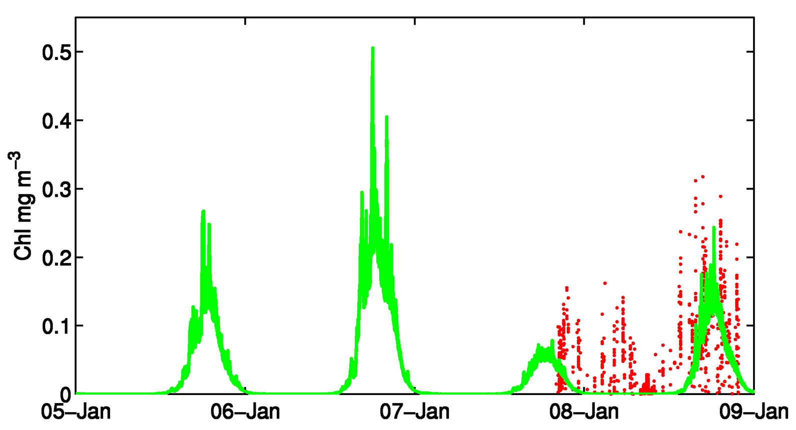
The model describes diazotrophy according to the physiology of *Trichodesmium*, taking into account a growth dependence on light, temperature, iron and phosphorus. Tri takes up DIN and meets its N demand additionally by N_2 fixation. Both Phy and Tri can take up DIP, whereas DOP is only accessible to Tri, based on the ability of *Trichodesmium* to exploit organic P (Dyhrman et al., 2006). All ecosystem variables have flexible N:P:Fe quotas which regulate both growth and nutrient uptake. Fe speciation and removal processes are described explicitly, based on Ye et al. (2009), for a better analysis of the impact of dust deposition on biology.

Modelled temporal and vertical distribution of *Trichodesmium*



The modelled *Trichodesmium* grows mainly in the upper 40 m and displays a strong seasonality with negligibly low concentrations in spring and summer and high concentrations in autumn and early winter. The highest concentrations (0.02 - 0.35 mg Chl m^{-3}) occur between September and November.

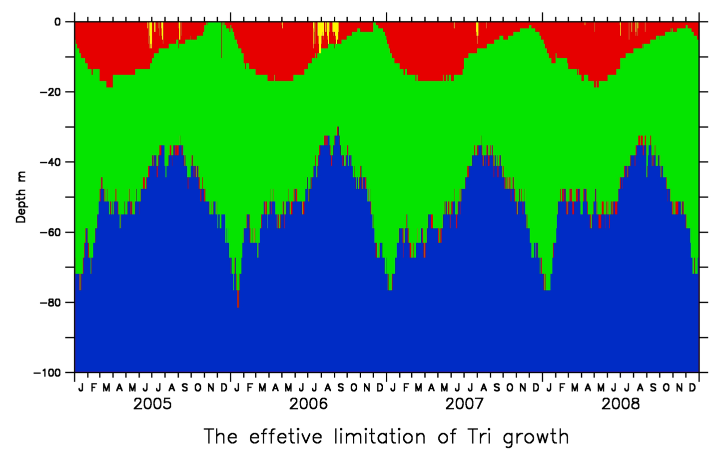
One year data (from Dec 2007 to Nov 2008) of cyanobacterial Chl a concentration was retrieved at ± 2° latitude and longitude around TENATSO, using the PhytoDOAS method (Bracher et al., 2009) combined with HPLC measurements. A similar seasonality of surface Chl a is demonsrated in both satellite (red) and model data (green).



Modelled growth limitation factors

The seasonality of Tri is predominantly determined by temperature.

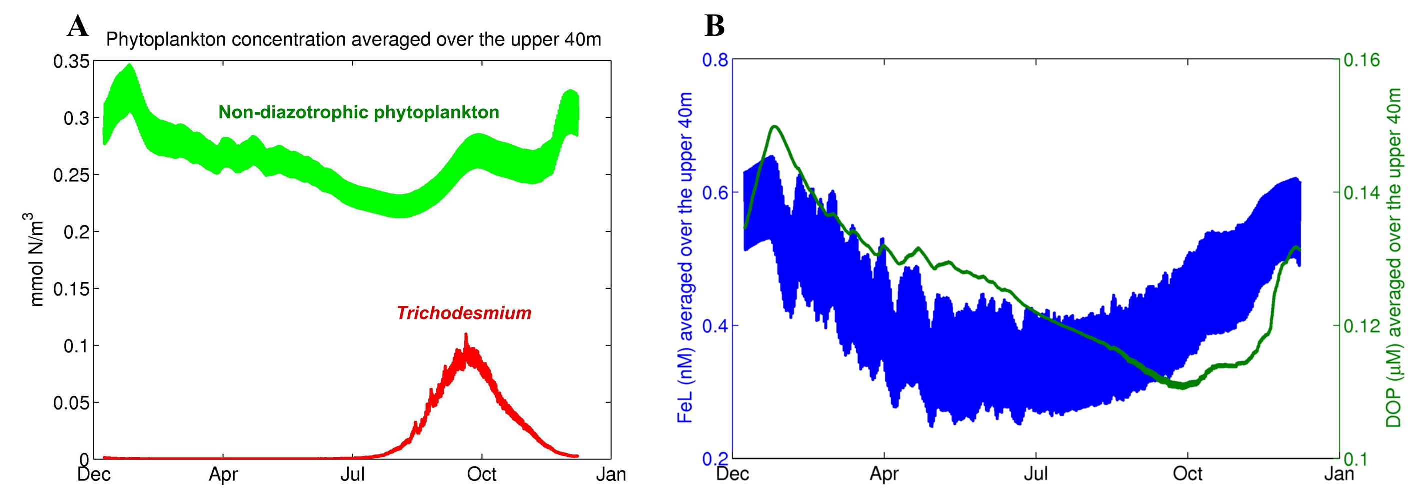
Within the upper 20m water layer, Tri growth is co-limited by Fe (yellow) and P (red), with more Fe-controlled at the beginning of its bloom and increasingly P- controlled during its bloom.



Below the upper water layer, Tri growth is mainly limited by light (green). No significant growth (blue) occurs further below.

Interactions between diazotrophs and non-diazotrophs

The modelled diazotrophs and non-diazotrophic phytoplankton bloom temporally differently (Fig. A).

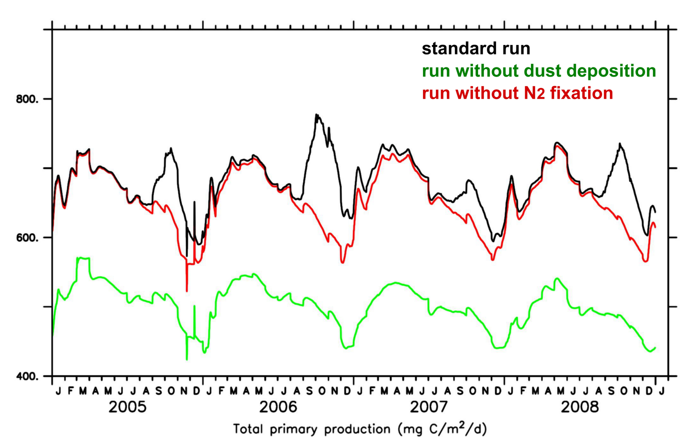


Competitive as well as mutually beneficial interactions have been found between modelled diazotrophs and non-diazotrophic phytoplankton:

1. High DOP availability after spring blooms of non-diazotrophic phytoplankton (Fig. B) enables diazotrophs to meet their P demand;
2. Newly fixed N by diazotrophs increases the growth of non-diazotrophic phytoplankton in autumn and winter significantly;
3. Fe consumption by non-diazotrophic phytoplankton earlier in a year reduces Fe availability (Fig. B) and accelerates Fe limitation of diazotrophs in summer. Shallower mixed layer and higher dust deposition in late summer/autumn alleviate the Fe shortage again;
4. Diazotroph blooms in surface waters reduces phytoplankton abundance deeper in the water column by light limitation.

Impact of dust deposition and diazotrophy on prim. prod.

Dust deposition provides a high amount of bioavailable Fe for all phytoplankton incl. *Trichodesmium* and enhances primary production significantly (black & green). A simple relationship between dust fluxes and the magnitude of N_2 fixation is however not found.



N_2 fixation, providing new fixed N for further primary production, is only seasonally important (up to 25%) (black & red), because we only considered *Trichodesmium* as diazotroph in the model and its high abundance occurs in autumn. Introducing other diazotrophs into the model may change this picture.

Outlook

We will further compare modelled interannual variability of Chl a with satellite-derived data.

The model description of N_2 fixation will be implemented in one 3D biogeochemical model, to study environmental controls on the distribution and magnitude of N_2 fixation in the Atlantic and in the global scale.

References
Mahowald, N. et al. (2003): Interannual variability in atmospheric mineral aerosols from a 22-year model simulation and observational data. J. Geophys. Res., D. Atmospheres, 108. **Dyhrman, S. T. et al. (2006):** Phosphonate utilization by the globally important marine diazotroph *Trichodesmium*. Nature, 439(7072):68–71. **Ye, Y. et al. (2009):** A model of Fe speciation and Biogeochemistry at the Tropical Eastern North Atlantic Time-Series Observation site. Biogeosciences, vol. 6, 2041-2061. **Bracher, A. et al. (2009):** Quantitative observation of cyanobacteria and diatoms from space using PhytoDOAS on SCIAMACHY data. Biogeosciences, 6(5):751–764.