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Diatom-driven carbon export during the North Atlantic Spring Bloom: coupled physical-biological modelling and variational data assimilation

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1. Motivation

The North Atlantic Spring Bloom is one of the main events that lead to carbon export to the deep ocean, driving CO_2 uptake from the atmosphere. The NAB08 experiment was carried out south of Iceland, where a Lagrangian float and four seagliders followed a phytoplankton patch, providing a 3-D coverage over time. The autonomously measured data was calibrated with *in situ* samples from three supporting cruises. During the experiment we observed a major export event of diatom aggregates. We have implemented this behavior in an ecosystem model describing the bloom, where a 1-D physical model is coupled to three biological model variants of different complexity. We applied variational data assimilation to optimize the models and compared them based on their performance in replicating the bloom and its associated carbon export.

2. Observed data

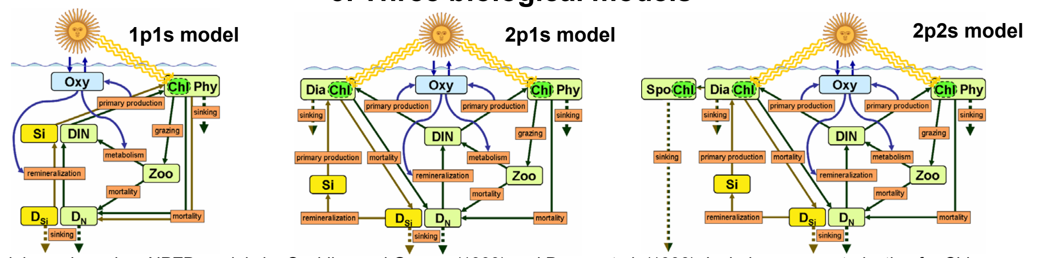
Lagrangian float

Operated south of Iceland April 4, 2008 - May 25, 2008. Drifted in the mixed layer and made daily profiles down to 250 m. Provided direct and proxy data for Temperature, Salinity, Chlorophyll, PON, Oxygen and DIN.

Bottle measurements

Ancillary measurements taken during a cruise on *R/V Knorr* May 2, 2008 - May 21, 2008. Provided bottle data on Silicate. Gave us insight into the evolution of the phytoplankton community and captured a massive sinking of diatom cysts at ~50 m/day, observed in spikes in optical measurements and in sediment traps.

3. Three biological models



Models are based on NPZD models by Oschlies and Garcon (1999) and Doney et al. (1996). Include a parameterization for Chl photoacclimation (Fennel and Boss, 2003; Geider et al., 1998), oxygen evolution and a silica cycle. Cysts in the 2p2s model represent the observed rapidly sinking diatoms - all model diatoms instantly convert into cysts once silicate concentrations fall below a critical level. The biological models are embedded into a 1D physical model (General Ocean Turbulence Model, www.gotm.net), implemented for the experiment location. It describes the top 200 m of the ocean with a vertical resolution of 1 m. It is forced with wind speeds, air pressure, air temperature, humidity and solar radiation from NCEP/NCAR reanalysis data set (Kalnay et al. 1996). Its temperatures and salinities are strongly nudged to their corresponding observations and mimic the physical conditions along the track of the float.

4. Data assimilation

Variational data assimilation varied biological model parameters to minimize the misfit between the model and observations. The misfit is measured by a cost function F:

$$F(\mathbf{p}) = \frac{1}{n}\sum_{i}^{n}\frac{(X_i^{obs} - X_i^{mod}(\mathbf{p}))^2}{\sigma_i^2}$$

An additional cost term, F_R, utilized the qualitative knowledge that phytoplankton community shifted from diatom dominated to small phytoplankton dominated between May 12 and May 16. The optimized model variables were *Chl*, *PON* (*Phy* + *Dia* + *Det$_N$* + *Zoo*), *DIN*, *Oxy* and *Si* (top 100 m). Cost function was minimized by a gradient descent routine (Gilbert and Lemarechal, 1989). To avoid local minima, we applied this routine many times for randomly chosen initial parameter values (Fig. 1).

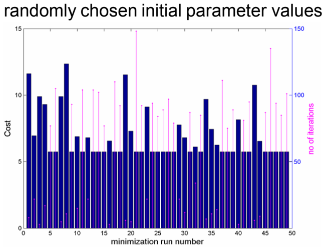


Fig. 1: Minimization results (1p1s model)

Conditioning of the minimization problem and *a posteriori* parameter errors were estimated by analyzing the Hessian matrix of the cost function (Fennel et al., 2001).

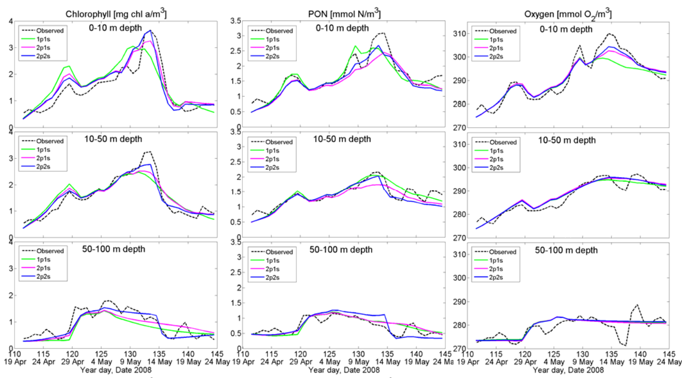
References

1. A. Oschlies, V. Garcon. 1999. An eddy-permitting coupled physical-biological model of the North Atlantic. Global Geochem. Cycles, 13: 135-160.
2. S.Doney, D.Glover, R.Najjar 1996 A new coupled, one-dimensional biological-physical model for the upper ocean: Applications to the JGOFS Bermuda Atlantic Time Series Study (BATS) site. Deep Sea Res. II, 43:591-624
3. K. Fennel, E. Boss. 2003. Subsurface maxima of phytoplankton and chlorophyll: Steady state solutions from a simple model. Limn. and Oceanogr. 48: 1521-1534.
4. R. Geider, H. McIntyre, T. Kana. 1998. A dynamic regulatory model of phytoplanktonic acclimation to light, nutrients and temperature. Limn. and Oceanogr. 43: 679-694.
5. Kalnay et al. 1996. The NCEP/NCAR 40-year reanalysis project, Bull. Amer. Meteo. Soc., 77, 437-470
6. J. Gilbert, C. Lemarechal. 1989. Some numerical experiments with variable-storage quasi-Newton algorithms. Mathem. Programming 45 (1989) 407-435.
7. K. Fennel, M. Losch, J. Schröter, M. Wenzel. 2001. Testing a marine ecosystem model: sensitivity analysis and parameter optimization. Journ. of Mar. Syst. 28: 45-63.

5. Model-data comparison

Model optimization obtained the following cost function minima:
1p1s model: F=5.57; 2p1s model: F=5.01; 2p2s model: F=4.60

Most of the optimized parameters were very similar between the models, except for those directly affecting zooplankton. The optimized 2p2s model shows the best match with the observations (figures below).



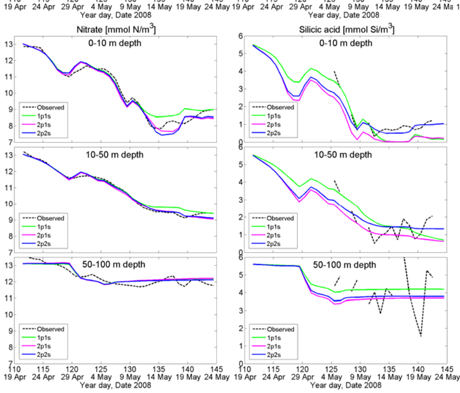


Fig. 2: Concentrations for the observations and three model variants

The simulated carbon export is similar for the three models. In the 2p2s model ~32% of the export comes with sinking cysts, which in the 1p1s and 2p1s models is replaced with more sinking detritus (Table 1).

	1p1s	2p1s	2p2s
Detritus	1.275	1.212	0.7496
Small Phy	0.078	0.0037	0.0151
Diatoms	-	0.3291	0.3349
Cysts	-	-	0.5099
Total	1.353	1.5448	1.6095

Table 1: Components of model carbon export at 100 m integrated over the time of the experiment [Mol-C/m^2].

Cyst formation is the main process ending the bloom in the 2p2s model (Fig. 3), what agrees with the spikes in optical measurements and the sediment trap data. In the other models the bloom ends mostly due to grazing, but we have no zooplankton data to verify this. General patterns of model small phytoplankton agree with the sparse nanophytoplankton flow cytometry data (Fig. 4), even though the later was not used in data assimilation.

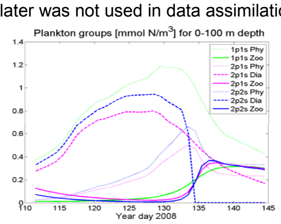


Figure 3: Concentrations of plankton groups, 0-100 m.

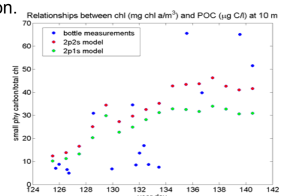


Figure 4: Ratio of small phytoplankton carbon to total chlorophyll at 10 m in model and from bottle flow cytometry.

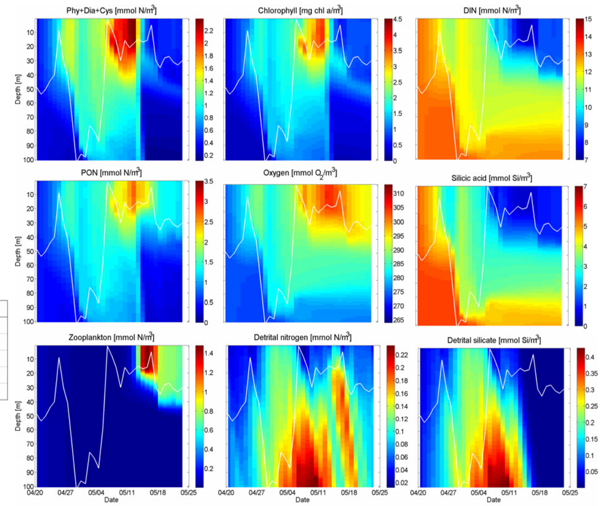


Figure 5: Depth-time profiles of variables simulated with the 2p2s model. White line represents the mixed layer depth.

6. Conclusions

- Increasing model complexity improved the match with observations, the 2p2s model is most successful
- Silica cycle is important for modelling the Spring Bloom – it is likely the only limiting nutrient
- Diatom cyst formation and rapid sinking during silica deficiency best explain the decline of the bloom
- 1p1s and 2p1s models must have high grazing timed with silica depletion to achieve a similar result
- Some zooplankton observations would be useful in the future to verify the importance of grazing
- Carbon export at 100 m in 32 days, predicted by the 2p2s model is 1.61 Mol-C/m^2, largely diatom-driven