Inter-annual variability in the timing of the spring phytoplankton bloom in the Norwegian Sea: causes and possible consequences on a climate change perspective.

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Introduction

Understanding and quantifying the processes behind the production and fate of the organic matter by phytoplankton in the ocean has long been a key field in the study of marine ecosystems. While previously the main interest was closely related to the assesment of the ocean´s capacity for food production, in the past few decades the concern about climate change and its consequences have given this kind of studies a considerable revigoration. In short, the further transport of biogenic matter in the open ocean follows two main paths, one towards higher trophic levels in the food webs mainly by zooplankton grazing and the other towards deeper layers by sedimentation when grazing is absent or significantly reduced. In a way these two processes are competing ones and their relative success upon each other depends on a series of physical and biological factors. In a climate change perspective it is the latter process on which the focus becomes most important since it affects the rate at which the sequestering of inorganic carbon penetrating the ocean takes place. In the present poster an attempt to charactherize these processes as they occur in the Norwegian Sea is made. The study is based on a time series of physical, chemical and biological observations collected at the Ocean Weather Station Mike (OWMS, 66 N; 02 E) during the period 1990-2003.

Formation of the upper mixed layer and spring bloom

The Norwegian Sea is charachterized by a relative deep and homogeneous winter mixed layer that extends down to 300-400 meter depth. During late winter and early spring the warming up of the surface layers gradually leads to its stratification and the formation of an upper mixed layer, essential for the development of phytoplankton. However this process can vary from year to year as it is shown in figure 1.

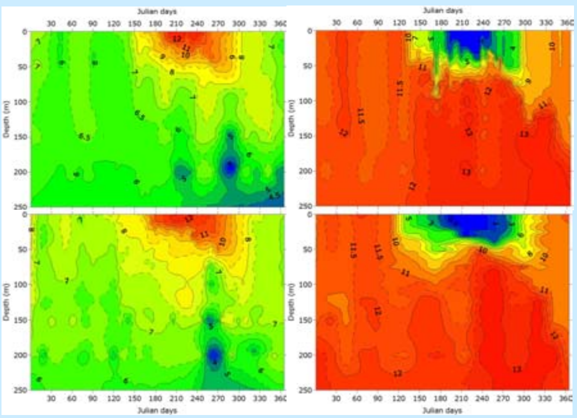

Figure 1. Vertical distribution of temperature (ºC, left) and nitrate (µmol l^{-1}, rigth) at OWSM in 1997 (upper panels) and 1998 (lower panels).

Winter temperatures in 1998 were higher than in 1997 and the winter mixed layer was also more stratified. The same was the case with salinity indicating that the difference in the watermass properties between the two years was probably related to differences in the advective transport from the south. This resulted in an earlier stratification in 1998 by about 3-4 weeks compared with 1997 a fact that it is also reflected in the nitrate distribution indicating an earlier start of the phytoplankton growth in 1998.

During the investigated period the pattern of phytoplankton development in the first half of the year was quite similar from one year to another. Three main phases were identified in this period by looking at the average cholorophyll *a* concentration in the upper mixed layer(UML). Figure 2 shows these three phases for a particular year (1998).

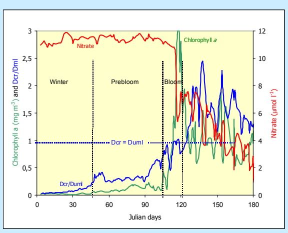

Figure 2. Average chlorophyll a (mg m^{-3}, green line) and nitrate (µmol l^{-1}, red line) concentrations in the UML at OWSM together with the Dcr/Duml ratio (blue line) during the first half of 1998.

The first phase called "winter" extends from January through February and it is charachterized by very low chlorophyll *a* concentrations, high nitrate levels and a very low Critical Depth/UML Depth ratio(Dcr/Duml).
The second one called "prebloom" show a modest increase in chlorophyll *a* as well as an increase in the Dcr/Duml ratio and extends for about two months.
The third phase is the "bloom" period itself charachterized by a rapid increase both in chlorophyll *a* and the Dcr/Duml ratio as well as a strong reduction in nitrate concentrations. The bloom attained its maximum value after the Dcr/Duml ratio reached values very close or larger than one supporting the theory of Sverdrup(1953).
The observed pattern in phytoplankton development was remarkably similar on every year of the investigated period.

Interannual variability in the timing of the spring bloom

The "prebloom" and "bloom" phases in the phytoplankton development in the Norwegian Sea are of utmost importance for a succesful reproduction of the main grazer, the copepod *Calanus finmarchicus* (Niehoff et al,1999). While the "prebloom" phase is mainly involved in the reproduction process, the "bloom" provide the necessary food for the new generations. Thus, the variability in time at which these two phases occurs is critical for a succesfull recruitment of copepods. Figure 3 shows the variability with time of the peak of the spring bloom and when the Dcr/Duml ratio reachs unity.

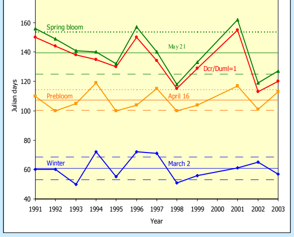

Figure 3.Year to year variation in the different phases of the development of phytoplankton at OWSM in the period 1991-2003. Continuous lines represent the period and broken lines one standard deviation.

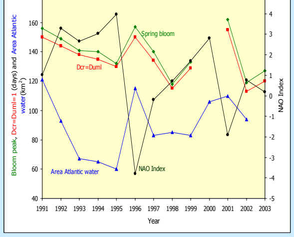

Figure 4.Year to year variation in the NAO Index, the cross sectional area of Atlantic water (S>35) at the Svinøy section, the time of the peak of the spring bloom and the time when Dcr/Duml=1.

The winter and prebloom phases shows lower variability with time than the bloom phase and with few exceptions they occur inside a standard deviation window. The time at which the spring bloom reachs its maximum is more variable and occurs just a few days after the critical depth equals the depth of the upper mixed layer. It is clear from these data that the physical conditions, especially the stabilisation of the water column, are of utmost importance for the development of the spring bloom.

In a climate perspective then, it is important to couple this variability to changes in the physical oceanography of the are. Figure 4 shows that the timing of the spring bloom is correlated with the cross sectional area of Atlantic water at the Svinøy section measured during April-May. The section is located just south of the OWSM. At the same time this cross sectional area is correlated with the NAO index. These facts indicates that during years with low NAO index a thicker layer of Atlantic water is observed leading to a slower stabilisation of the upper mixed layer and a late bloom. In contrast during years with high NAO index the layer of Atlantic water is shallower allowing an earlier stratification and spring bloom.

Possible consequences of the variability of the timing of the spring bloom

Taking into consideration the tight coupling between the development of phytoplankton and the reproduction and recruitment of *Calanus finmarchicus* it is quite obvious that at the present time most of the material produced by phytoplankton is transferred up in the food web. This is corroborated by the facts that little sedimentation of phytoplankton (particulate organic carbon) to the deep layers has been observed (Peinert et al.,1987) as well as the accumulation of relatively large amounts of dissolved organic carbon at intermediate layers (Børsheim and Myklestad, 1997).

As long as the organic carbon does not reach layers below the winter mixed layer, it will be exposed to remineralisation and return to the upper layers as it does in the Greenland Sea (Miller et al.,1999). Thus, the sequestering of inorganic carbon by biogeochemical processes will be constrained (Noji et al., 2001).

There is still uncertainties about the dimenssion of eventual climate changes as a result of the increase in emission of greenhouse gasses but there is almost a consensus that there is an ongoing global warming. Eventually this warming will be more pronounced in high latitude regions than at lower ones. It is impossible based on this short data series to draw any certain conclussion but it is still worth to do some excersises to get some idea of what could hapen if the marine climate changes.

It is also well known that two of the major driving forces for the currents system in the Norwegian Sea are the thermohaline circulation and the wind system over the North Atlantic. The latter is at a large degree determined by the NAO. Both forces acts are closely related making it almost impossible to separate them.

Based on the results presented here it is clear that in years with high NAO one would expect a shallower and smaller layer in the outer kernel of Atlantic water in the Svinøy section (Blindheim et al, 2000). It is the water from this kernel that flows through the area were OWMS is situated. The less thicker body of Atlantic water during these years will allow a more rapid stratification of the upper layers due to insolation and eventually will lead to an early development of phytoplankton. In the opposite case of low NAO a thicker layer of Atlantic water the development of stratification would be much slower and the phytoplankton bloom will take place later.

In the Barents Sea the time at wich the spring bloom takes place has enormous importance for the development of zooplankton (Rey et al., 1987) mainly due to that earlier blooms take place when cold Arctic waters advects southwards ther Polar front. The colder water retards the reproduction processes of *Calanus finmarchicus* creating a mismatch between the bloom and the ability of the zooplankton population of utilising it. This seems not to be the case in the Norwegian Sea since the difference in water temperature between years with earlier and later blooms is not as large as in the Barents Sea and will not markedly affect zooplankton development. Furthermore, *Calanus finmarchicus* in the Norwegian Sea is very well adapted to the conditions here (Melle et al., 2004).

Climate models predict temperature rises of 2-4ºC in the Northeast Atlantic and a reduction in Atlantic inflow to the Norwegian Sea of about 25%. Most probably this will not change markedly the situation as it is today. However, an increase in air temperature will probably also lead to an increase in water temperature. This will allow better growth conditions for zooplankton probably with the appearence of a second generation during late summer, at least in the southern part. This will exert even a larger grazing pressure on phytoplankton diminishing even more the sedimentation of particulate material and the sequestering of inorganic carbon. One aspect that remains uncertain is the role of dissolved organic carbon that in such a scenario will probably increase.

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