Biogeosciences Discuss.,
https://doi.org/10.5194/bg-2018-94-AC2, 2018

Biogeosciences Discussions Open Access EGU

Interactive comment on "Coastal primary productivity changes over the last millennium: a case study from the Skagerrak (North Sea)" *by* Anna Binczewska et al.

Anna Binczewska et al.

anna.binczewska@usz.edu.pl

Received and published: 19 June 2018

Response: We appreciate constructive comments and suggestions from anonymous referee 2. Responses to the review are below.

Reviewer 2: The paper presents two records of benthic foraminiferal assemblages and geochemical analyses from the northern deep Skagerrak region. The records are excellent, presenting high-resolution data for the last millennium. The strength of the paper is especially the fact that data from two neighboring cores are presented, as provides evidence of a general pattern. The paper is overall well-written and clearly presented and I believe that it fits well within the scope of the journal.

Printer-friendly version

Discussion paper

However, the ms has a tendency to focus too much on local conditions and comparison to relatively few previous studies. It would therefore benefit from including information from a broader range of study sites as well as from other types of records, including terrestrial and lacustrine records. Also more direct comparisons between records as well as an improved precision of the discussion of water masses is needed. Finally, not all data (e.g. Mg/Ca) are actually used to any significant extend in the discussions:

Response: The concerns about the discussion and interpretation of the data are addressed. We will add broader information and more details to the discussion about water masses and Mg/Ca (also see further information below).

Reviewer 2: A key element of the paper is the link between the record and the North Atlantic Oscillation (NAO). A number of studies have suggested a more positive phase of the NAO during the MCA and a negative phase during the LIA. However, the here the authors only refer to one study without taking into account that other, earlier, studies have also made this suggestion (e.g. from off Portugal, in the Labrador sea/West+East Greenland etc.).

Response: The sentence: “In contrast, the North Atlantic Oscillation (NAO) reconstruction by Trouet et al. (2009) suggests a tendency for prevailing positive NAO conditions during the MCA and hence, south-westerlies dominating the hydrographic and meteorological regimes during winter.” have been changed to: “In contrast, the North Atlantic Oscillation (NAO) reconstructions by Trouet et al. (2009), Olsen et al. (2012), Faust et al. (2016), among others, all suggest a tendency for prevailing positive NAO conditions during the MCA and hence, south-westerlies dominating the hydrographic and meteorological regimes during winter.” We will add more references concerning the NAO through the text, accordingly.

Reviewer 2: Also, since the present manuscript provides a high-resolution records, these data should in fact be plotted vs. the high-resolution NAO reconstructions (Trouet et al, as well as vs. other high-resolution records such as those by Olsen et al 2012

Printer-friendly version

Discussion paper

and Faust et al 2016).

Response: We would like to thank the reviewer for the advice on papers by Olsen et al. (2012); Faust et al. 2016) and Nejse et al. 2000. We have included information and data from these studies in the revised manuscript, presenting direct comparison between those records and ours. We will also include reference to other relevant studies e.g. Bakke et al. (2008). We have plotted three suggested NAO reconstructions vs. our data. Please find enclosed Fig. 6.

Reviewer 2: It would be very interesting to see, if the overall quite well-known trend of positive NAO during the MCA and negative NAO during the LIA is also seen at shorter, decadal/multidecadal time scales. Whether such a correlation between productivity and NAO cannot be verified, it would be valuable information. Olsen, J., Anderson, N.J, Knudsen, M.F, 2012: Variability of the North Atlantic Oscillation over the past 5,200 years. Nature Geoscience 5, 808–812, doi:10.1038/ngeo1589 Faust, J.C., Fabian, K., Milzer, G., Giraudeau, J., Knies, J., 2016: Norwegian fjord sediments reveal NAO related winter temperature and precipitation changes of the past 2800 years. Earth and Planetary Science Letters 435, 84-93.

Response: While the long trend of positive NAO during the MCA and more negative NAO during the LIA correlated well with the defined in this ms productivity periods (best seen when correlated with NAO reconstruction by Faust et al. 2016, Fig.6), the correlation at the shorter time scale is harder to address. This is due to the dating uncertainties of the different records e.g. the uncertainty of the 14C dates in our records vary between 30 and 60 years, in records by Olsen et al (2012) from $\pm$5 to $\pm$35. Also, the relation between NAO and productivity at the decadal/multidecadal time scale could be better justified by looking at the high resolution data from the short cores (MUCs) as well as instrumental records covering last $\sim$120 years and comparing them to decadal trends in the NAO reported by e.g. Hurrell (1995). We intend to show the NAO-productivity correlation at the decadal time scale in the next manuscript which is currently being prepared by Binczewska et al.

Reviewer 2: The study region is influence by several different water masses, including local outflow of low-salinity water from riverine outflow, saline Atlantic water and more intermediate salinity water as a mixture of North Sea and riverine waters (e.g. the Jutland Current). However, in the presentation of the water masses, it is not always clear at which levels in the water column these water masses are found, nor whether they also influence the actual study sites. This problem continues throughout the discussion and the one gets the impression that either there is increased Atlantic water or increased low-salinity water. However, stratification could allow both. Thus, the discussion need to be much more precise.

Response: We have modified the 'study area' as follow: "The Skagerrak is located in the northeastern part of the North Sea, connected to the Baltic Sea through the Kattegat (Fig. 1). The basin has a mean water depth of 210 m and a sill depth of 270 m. With a maximum depth of 700 m the Skagerrak represents the deepest part of the Norwegian Trench (Rodhe, 1996). The area is characterised by an anticlockwise circulation and complex hydrography. The surface circulation (<30 m) is to a large extend dominated by a surface current consisting of inflowing saline water from southern North Sea and the North Atlantic and outflowing less saline water from the Baltic Sea (Danielssen et al., 1997). The inflowing nutrient-rich surface water flows along the Danish coast driven by the Southern Jutland Current (SJC) and the Northern Jutland Current (NJC) while the outflowing Baltic Sea water (BW $\sim$20 – 30 psu) flows as the Baltic Current (BC) along the Swedish west coast towards the northeast Skagerrak where it merges with the NJC and turns to the northwest as low saline Norwegian Coastal Currant (NCC) (Rodhe, 1996; Rydberg et al., 1996). The water flowing from the Skagerrak towards the Norwegian Sea (NCC) partly recirculates to the western Skagerrak (Rodhe, 1996). The surface water has a high nutrient concentration mostly due to the freshwater input via rivers draining from the Norwegian south coast, German and Danish east coasts, and the Baltic catchment area but also the upwelling of the underlying nutrient-rich Atlantic water is considered to be an additional nutrient supply (Gustafsson and Stigebrandt, 1996; Rodhe, 1996). As a consequence of the mixing of different water types and the high freshwater input enhanced by precipitation, the upper layer of the surface water has low salinity (25 – 32 psu) and is determined as the Skagerrak Coastal Water (4.5 – 10 °C). The water below, the intermediate layer (30 – 270 m) is referred to as Skagerrak Water (32 – 35 psu, 4.5 – 10 °C). The Skagerrak Water is driven by the subsurface circulation (Andersson 1996). The deep water layer below sill depth (>270 m) is dominated by Atlantic Water and is recognised as the Skagerrak Basin Water (>35 psu, 5.5 – 6.5 °C) (Aure and Dahl 1994). The subsurface circulation (below 30 m water depth), consists of nutrient-rich Atlantic deep water (AW >35 psu, 5.5 – 8.5 °C) flowing though the norther North Sea, and the water from the central and southern North Sea (NSW ~31 – 35 psu) (Rodhe 1996). The inflowing water follows the southern side of the Norwegian Trench to enter the Skagerrak in its central part, where can be mixed with fresh surface-water and flows out as the NCC (Winther and Johannessen 2006). Large-scale atmospheric systems and regional meteorological factors (e.g. precipitation and storms) influence the flow regime creating a high-dynamic system in the upper layer of the water column where water mixing is largely caused by the southwesterly winds (Gustafsson and Stigebrandt, 1996). At the same time, calmer hydrographic conditions are typical for the intermediate layer and the deep water down to ~ 400 m with a maximum water residence time of 3 months (Andersson, 1996). This is in contrast to the renewal of the deeper water below ~ 400 m which occurs every 1 to 3 years depending on the strength of the Atlantic water inflows (Aure and Dahl, 1994; Rodhe 1996), which closely correlate with the NAO index (Brückner and Mackensen, 2006)."

We hope that presented above the water masses description is more clear hence we will follow this description while improving the discussion section.

Reviewer 2: In this context, I do agree that the increased flux of planktic foraminifera indicated increased inflow of Atlantic water. However, how sure are the authors that the planktic foraminifera are in fact locally produced and not brought in from the Atlantic via the currents? The planktic foraminifera may not be autochthonous and even if they are, they would likely not represent direct surface waters. Thus, this inflow may not have occurred right at the surface, but rather as a subsurface current, thus still allowing an increased surface-outflow of lower-salinity waters.

Response 2: In the foraminiferal assemblage we found mostly large test sizes of G. bulloides and N. pachyderma and small tests of G. glutinata and G. uvula. This wide range of size (adults and juveniles) suggests that the planktonic foraminifera found in the Skagerrak cores were living in nearby water masses (Murray; 1976). Because waters with suspended sediment are not favourable for the planktonic foraminifera (which is also seen from their relatively low absolute abundance), it is possible that planktonic foraminifera were floating below the surface water level. Moreover, the depth habitats in the water column of planktonic species found in our record was reported by e.g. Jonkers et al. (2010) and Schiebel et al. (2017). According to those studies N. pahyderma dwells at 50 – 100 m of the water column and has the maximum calcification at 100 – 200 m, while G. bulloides dominates waters above thermocline at < 60 m, G. uvula occurs in highest amount in the surface waters and G. glutinata prefers the upper 50 m of the water column.

Murray, J. W. 1976: A method of determining proximity of marginal seas to an ocean. Marine Geology, 22: 103-119. Jonkers et al. 2010: Seasonal stratification, shell flux, and oxygen isotope dynamics of left-coiling N. pachyderma and T. quinqueloba in the western subpolar North Atlantic, Paleoceanography, 25, PA2204, doi:10.1002/palo.20018, 2 Schiebel et al. 2017: Modern planktic foraminifers in the high-latitude ocean, Marine Micropaleontology 136, 1–13

Reviewer 2: In the discussions on whether the changes in productivity are primarily liked to the influx of Atlantic water or if it could be linked to wind mixing during episodes of stronger winds and/or linked to changes in runoff from land liked to precipitation, it would be relevant to also compare with precipitation data. Here, e.g., studies of mass balance in Norwegian glaciers (e.g. Nesje et al 2000) as well as lake studies would be relevant. Nesje, A., Lie, Ø. And Dahl, S.O. 2000: Is the North Atlantic Oscillation reflected in Scandinavian glacier mass balance records? Journal of Quaternary Science 15, 587-601.

Response: We thank the reviewer for an advice on study by Nesje et al. (2000). We have plotted productivity data versus winter precipitation (Nesje et al; 2000), however the resolution of those data is too low over the last 1100 years to add significantly to the discussion. However, we will instead do a comparison to winter precipitation data from Bakke et al. 2008, where it looks like the precipitation has an overall decreasing trend throughout the last 1100 years. We will expand the discussion with presented in Fig. 6 precipitation information, accordingly.

Reviewer 2: Another point to raise is the actual use of the data. The dataset includes benthic foraminiferal assemblage studies, including factor analyses, planktic foraminiferal concentrations (no details on species distribution, so I assume that this was not analyses?), Mg/Ca, Mn/Ca, and stable carbon and oxygen isotopes.

Response: We found the same planktonic species at both studied locations. We did identify planktonic foraminifera to species level in each analysed sample. However due to their overall low abundance we prefer to present assemblage as total number of planktonic individuals. In line with both reviewer 1 and 2 comments we will use more of the data more actively in the revised discussion.

Reviewer 2: However, the geochemical data is only used for calculating bottom-water temperatures, and these temperatures are more or less accepted without any further discussions. The reliability and uncertainly of the data needs to be taken into account. Thus, the discussions on the palaeoproductivity is almost solely based on the benthic foraminiferal assemblages. The benthic foraminifera are good indicators, but since so much more data exist and are presented, they should also be used properly in the discussions.

Response: The discussion section will be revised according to the comments. In line with suggestions from Reviewer 1 we have added the uncertainties to the data and

Printer-friendly version

Discussion paper

information on uncertainties, and thereby we will consider to what degree we can be confident in how we interpret the data. In the revised version we will also use the other records presented (Mg/Ca, isotopes, now calculated and added δ18Osmow) more actively in the discussion.

Reviewer 2: Finally, despite an introduction trying to build a link between this study and the understanding of the consequences of greenhouse gas emissions, it the actual significance of the study region is not clear: Why is Skagerrak relevant? Because it represents and intermediate area between the open ocean and coastal regions?

Response: We have made this point clear by adding information to the introduction and modifying the paragraph on Pg 3, line 16 – 29, as follows: 'Coastal zones are among the most productive marine regions characterised by high: atmospheric CO2 uptake, organic matter accumulation and decomposition (e.g. Hjalmarsson et al., 2010). The Skagerrak, located between the North Sea and the Baltic Sea and in the close proximity to land, has many potential nutrient sources, such as the North Atlantic, Baltic Sea, North Sea, as well as continental discharge and river runoff (Aure and Dahl, 1994; Andersson, 1996; Gustafsson and Stigebrandt, 1996). Upwelling and precipitation further increase the nutrient supply to the surface waters, additionally stimulating productivity in this region (Pingree et al., 1982; Aure and Dahl, 1994; Fonselius, 1996). The North Sea and the Skagerrak absorb large quantities of atmospheric CO2 via the biological pump (1.38 mol C m-2 yr-1 and 1.2 mol C m-2 yr-1, respectively), thus play a large role in the carbon cycle (Thomas et al. 2005; Hjalmarsson et al., 2010). The Skagerrak acts as a main depositional basin for about half of the refractory carbon produced in the North Sea and for a high amount of labile organic matter imported with waters of the near-bottom current from the Danish coast or caused by intense algal blooms (Boon et al., 1999). Input of nutrients largely regulate food webs, which makes nutrients of great economic importance for the coastal areas worldwide (Micheli, 1999; FAO, 2016) and in the Skagerrak nutrients are particularly important for the Nordic fisheries (Hop et al., 1992; Iversen et al., 2002; Olsen et al., 2004; Skogen et al., 2007). Fisheries

Printer-friendly version

Discussion paper

and aquaculture sectors of the Skagerrak, commercially valuable for the Scandinavian nations, also make a relevant contribution to a growing global demand for food, which will largely rely on coastal regions to host a major part of food production in the future (e.g. FAO, 2013). Effects of increased primary production range from positive impacts on growth, size and reproduction of fish and shellfish populations to disruptive alterations in the food webs, thus yielding or reducing the profit rates of fisheries (Hop et al., 1992; Micheli, 1999; Iversen et al., 2002; Olsen et al., 2004, 2005; Breitburg et al., 2009; FAO, 2016). Negative changes in trophic levels of the Skagerrak ecosystem have been attributed to overfishing (Cardinale and Svedäng, 2004), however, ongoing studies alert about adverse impact of increased nutrient inputs driving heavy phytoplankton blooms and eutrophication in the region (e.g. Baden et al., 1990; Aure et al., 1996; Breitburg et al., 2009). Eutrophication causes high demand and depletion of oxygen in the bottom waters, which affect species diversity, morphology and population growth, and forces organisms to migrate (Rosenberg et al., 1990; Conley, 2009). Thus, to better understand the ongoing and possible future productivity changes and associated environmental effects, more historical studies are needed.'

Reviewer 2: Also the actual relevance of the outcome of the study to the problems raised in the introduction is not clear and should be made clear in the conclusions. It is an interesting and relevant study, but please make it clear to the reader, too.

Response: After revising discussion part we will make sure that the conclusions addresses the research questions raised in the introduction.

Minor comments: Reviewer 2: Latin grammar rules means that the name of the species should be "Melonis barleeanus", not "Melonis barleeanum". Response: We have changed everywhere to Melonis barleeanus.

Reviewer 2: Are you sure that Cassiculina neoteretis is present in the material? If yes, this could indicate an high influx of deep Atlantic or even Nordic Sea water. "

Response: We sincerely thank the reviewer for underlining this feature. The identification of C. laevigata vs C. neoteretis in the Skagerrak material was done based on studies by Mackensen and Hald (1988) and Seidenkrantz (1995). C. neoteretis was also found there by other studies e.g. Erbs-Hansen et al (2011). Since relative abundance of C. neoteretis exceeds 5% only in two samples in each of the cores we considered it as a rather rare species. However, we have now had a closer look at the changes in the C. neoteretis records We observed a peak of high relative abundance of C. neoteretis between $\sim$ 1750 – 1800 years which correlates well with a drop in BWT and δ18O at the same time, indicating colder bottom water temperature. Therefore, it is possible that this is an indication of a higher influx of deep Atlantic Water or even Nordic Sea waters (Mackensen and Hald 1988, Seidenkrantz 1995). We will add this information in the revised manuscript.

Reviewer 2: Page 4, lune 25-30: It is not quite clear from the description of the water masses, which ones are surface waters, intermediate waters and bottom waters. One for one water mass is the depth in the water column provided. As the depth of outflowing/inflowing waters is very important, this must be made clear. It also needs to be specified very clearly, which water mass sweep the actual study sites in the deep Norwegian Trench. Response: See the comment above regarding water mass clarification.

Reviewer 2: Page 5, line 12-15: It should be pointed out specifically that both cores are taken from the deep Norwegian Trench. Response: We have added a sentence to the material and method section as follows: "Both cores are taken below sill depth within the deep waters of the Norwegian Trench."

Reviewer 2: Material: please provide a short, overall description of the sediment in the two cores. We have added a following sentence: "Both cores consist of mostly soft organic-rich clay and show no significant changes in grain size and lithology throughout the records."

Reviewer 2: Factor loadings are provided and used in the discussions and presented well in the final figure of proxy comparison. However, in order to evaluate the results of factor analyses, the authors should consider actually plotting them vs age in a diagram comparing them to the faunal data. Response: We have modified the figure with foraminiferal fauna according to the comment.

Interactive comment on Biogeosciences Discuss., https://doi.org/10.5194/bg-2018-94, 2018.

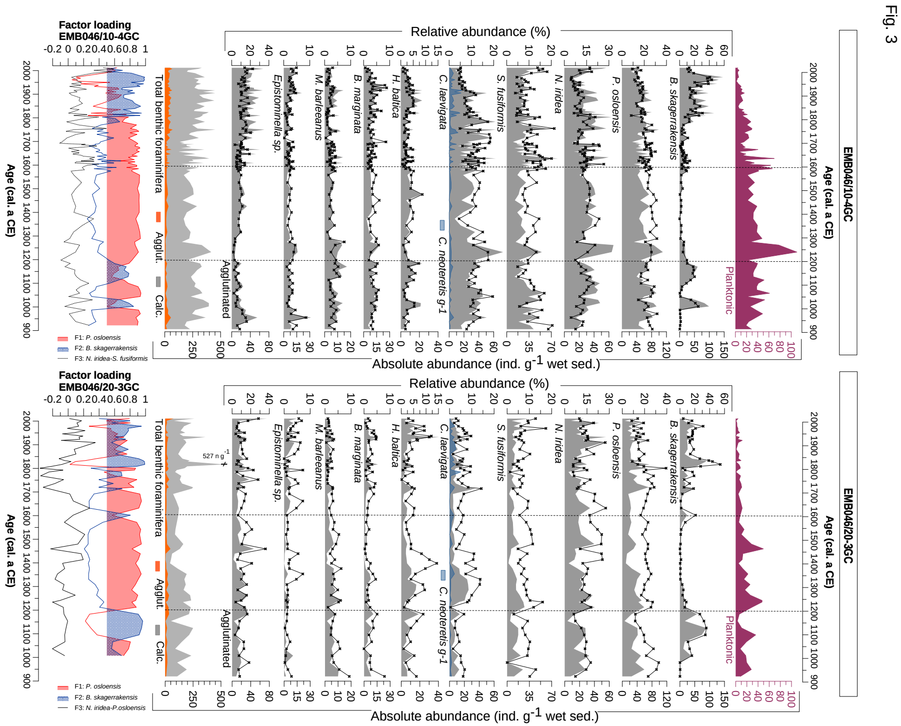

Fig. 1.

Printer-friendly version

Discussion paper

Interactive comment

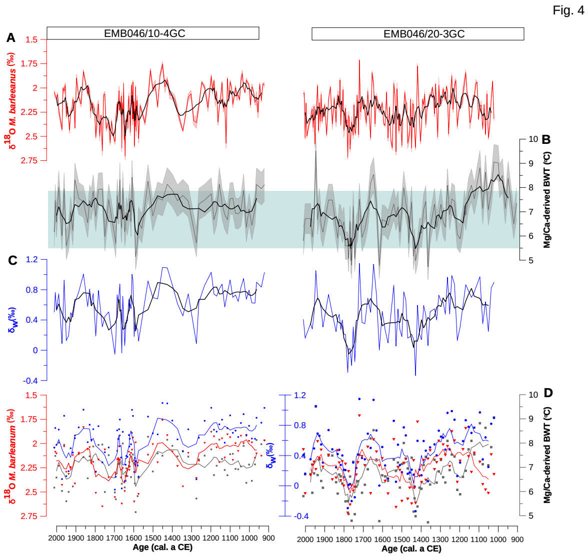

Fig. 2.

Printer-friendly version

Discussion paper

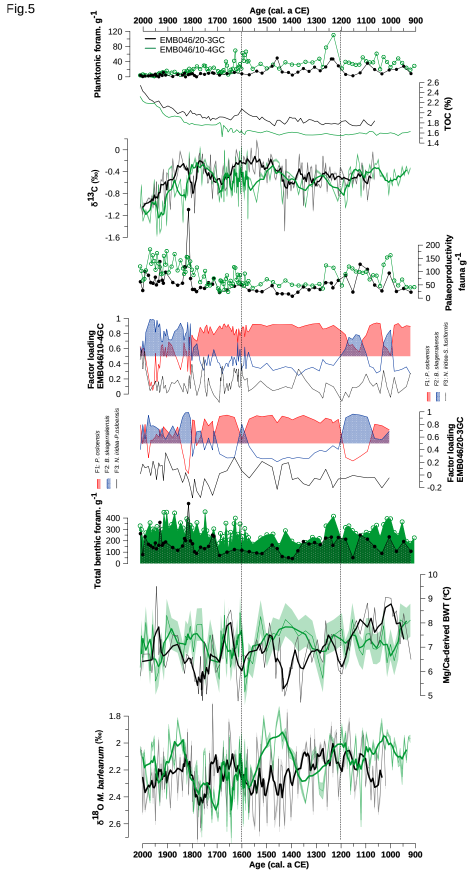

Fig. 3.

Printer-friendly version

Discussion paper

Fig.6

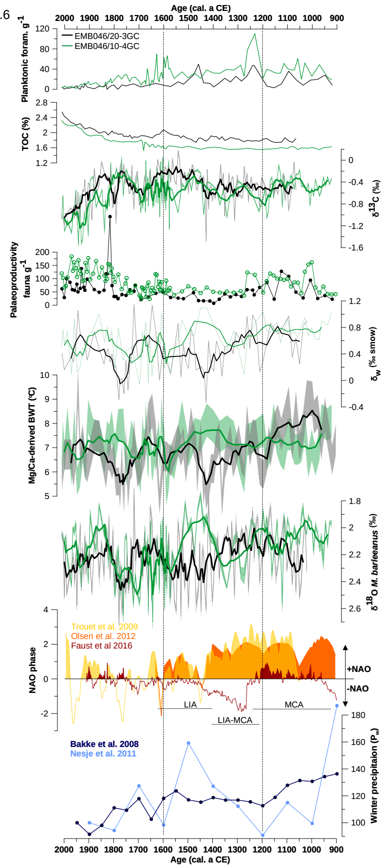

Fig. 4.

Interactive comment

Printer-friendly version

Discussion paper

Figure capture

Fig. 2 Age model description will be presented in the new version of the manuscript.

Fig. 3 Foraminiferal assemblages including dominant and accessory benthic species for both cores (EMB046/10-4GC and EMB046/20-3GC), and CABFAC results. Absolute abundance is shown as grey filed, while relative abundance as black curve with symbols. The absolute abundance of total benthic foraminifera is a sum of all species: agglutinated (Agglut.) and calcareous (Calc.). Dashed lines divide record into 3 periods of most pronounced palaeoproductivity changes, which are discussed in the text.

Fig. 4 (A) Oxygen stable isotopes ($\delta^{18}O$); (B) the Mg/Ca-derived bottom water temperature (Mg/Ca-derived BWT); (C) the stable oxygen composition (δw), of both studied cores against age. The errors bands represent uncertainties of the records. (D) Figures include data from depths at which data of all proxies (δ18O, Mg/Ca-derived BWT, δw) are available (symbols). The curves correspond to 5-points running average. Grey box indicates range of instrumentally recorded temperatures of the time period between 2009 and 1924 years from the area between 57°.17–58°´N and 8°–9°.79´E at 300 – 340 dbar (ICES 2010).

Fig. 5 Comparison of absolute abundances of planktonic foraminifera, total organic carbon (TOC), stable carbon isotope (δ13C), absolute abundance of palaeoproductivity fauna, CABFAC results, absolute abundance of total benthic foraminifera, Mg/Ca-derived bottom water temperature (Mg/Ca-derived BWT), oxygen stable isotope (δ18O) between two studied sediment cores EMB046/10-4GC (green curves) and EMB046/20-3GC (black curves). The thicker curves correspond to 5-points running average. The errors bands represent uncertainties of the records. Dashed lines divide record into 3 periods of most pronounced palaeoproductivity changes, which are discussed in the text.

Fig. 6 Comparison of absolute abundances of planktonic foraminifera, total organic carbon (TOC), stable carbon isotope (δ13C), absolute abundance of palaeoproductivity fauna, CABFAC results, absolute abundance of total benthic foraminifera, the stable oxygen composition (δw), Mg/Ca-derived bottom water temperature (Mg/Ca-derived BWT), oxygen stable isotope (δ18O) between two studied sediment cores EMB046/10-4GC (green curves) and EMB046/20-3GC (black curves). The reconstructions of the NAO index. The thicker curves correspond to 5-points running average. The errors bands represent uncertainties of the records. Dashed lines divide record into 3 periods of most pronounced palaeoproductivity changes, which are discussed in the text.

Fig. 5.