

Interactive comment on “Northward advection of Atlantic water in the eastern Nordic Seas over the last 3000 yr: a coccolith investigation of volume transport and surface water changes” by C. V. Dylmer et al.

C. V. Dylmer et al.

c.dylmer@epoc.u-bordeaux1.fr

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Answer to the guest editor and the Anonymous Referee n°2

We strongly appreciate the thorough review, editing and comments provided by the editor J. Knies and the Anonymous Referee n°2 on the present paper, which are indeed relevant and will strongly improve the manuscript in terms of method, results and discussions. We are addressing in the following both comments by J. Knies and Anonymous Referee n°2.

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General comments We changed the term “volume” to “strength” in accordance with the suggestions by Referee n°2 as our work indeed concerns the variability in the strength of the NAC (and tributaries) integrated over depth and not the transport by volume (Sverdrup). Also we do emphasize that the application of *G. muelleriae* (as a proxy for the strength variability of NAC) should not be seen as a proxy for surface water flow variations alone. Given the suggested southern origin of this species, we expect these coccoliths to be well mixed within the NAC and not strictly limited to surface water expression of the AW flow.

Methods: We avoided in first instance the use of coccolith concentrations (number of coccoliths/gr. dry sediment) as a paleo proxy for paleo-productivity in surface waters within this manuscript as we feared there might be biases by temporal changes in dilution by terrigenous material. Anonymous Referee n°2 doubts that the influence of terrigenous material on the paleoceanographic data in general within this area (especially with regard to the river transport) might be strongly affecting the coccolith records from our two northernmost core sites. We definitely agree with the fact that the terrigenous material does not primarily originate from river runoff and will correct this in the final manuscript. Nevertheless we still believe that the two northern sites are affected by differences in terrigenous dilution of the coccolith signals, as previous publications on historical sea ice distribution has clearly shown that lithogenic inputs from sea ice-derived material strongly contributed to the sedimentation around Bjornøya (and Kveithola trough) and west of Svalbard (within the main core of AW) (Vinje et al., 2001 and Dick and Divine, 2006) during the last centuries. Furthermore although figure 2 indeed shows overall similar sedimentation rates within the two cores in the order of 12-15 cm/1000 yrs, there are differences in the timing of local changes in sedimentation rates; hence we found it necessary to confirm the reliability of down-core concentration changes for a single core location by comparing it with species weight %, since relative abundances are not influenced by dilution (as long as counts are conducted according to the same amount of specimens - >300 in our case -). We'll include this topic in the “Methods” section of the revised version.

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Understanding the concern related to the error ranges in calculation of coccolith abundances (although the main changes mentioned within the paper are generally larger than 5%), we will specifically address this matter in the revised “Methods” section. According to Herlle and Bollmann (2004, Mar. Micropal. vol. 53) repeated analyses of a fine fraction sediment sample revealed that the applied funnel method can cause ~15% deviation in the bulk coccoliths absolute concentrations (and consequently on species-specific absolute concentrations). However, the concentration changes we are focusing on within our work (in order to infer past circulation changes) are large amplitude changes, always higher than this 15% error threshold. Also, the funnel method, given its set-up, does not induce any deviation in species relative abundances. Only the absolute number of counted specimens can statistically influence the reliability of relative abundances (species %). The revised version of the “methods” section will also include a reference to Andrulleit (1996) who found it statistically reliable, in terms of species relative abundance, to conduct the counting on a minimum of 300 coccolith specimens (which was the micropaleontological approach used in our analytical work).

Species-selected coccolith proxies: The overall dominating species in the coccolithophore community of the Nordic Seas are *Emiliana huxleyi* with generally high cell densities. Changes in the community are indeed (as added by reviewer 2) to a large extent controlled by changes in the abundance of this species. *C. pelagicus* was however found in medium-high cell densities up to 100×10^3 coccolithophores/L in several surface water studies (e.g. Baumann et al. (2000) north and northwest of their study area (as well as south of Iceland), Samtleben and Schröder (1992) in the Norwegian-Greenland Sea, and Dylmer et al. (in prep) across Fram Strait in September/October 2007). Hence we believe that the stated dominances of the two main species are correct although *Emiliana huxleyi* densities are higher than all other species.

Anonymous referee 2 stated that the “coccolithophore occurrence and distribution are certainly influenced by ecological parameters (temperature, salinity, nutrients, turbulence etc.) within this water mass and not by variations in its volume”. We agree on

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the fact that coccolithophores are strongly influenced by several ecological parameters of which temperature, turbulence, stratification, nutrients and irradiance are of outmost importance. However we consider important to highlight the influence of changes in the strength of the main Atlantic-derived surface/subsurface currents on these parameters. Increases in the inflow of AW would most likely cause changes both in sea ice melting (hence stratification) and temperature/salinity gradients (which define the location of the Arctic and Polar fronts), influencing the production of coccolithophores.

The editor and Anonymous Referee 2 raised the question of the application of the E/C ratio to reconstruct surface water masses in terms of “Arctic Water” and “Atlantic Water”. The original work by Baumann et al. (2000) indeed did not use the E/C ratio to define the dominating water masses. Instead they suggest that this ratio can be used as a proxy of the position of the Arctic Front within the Norwegian-Iceland-Greenland Seas (since the change in the dominating species as documented by the E/C ratio ($>$ or $<$ 1) within the surface sediments occurs at about the summer position of the Arctic front (Baumann et al., 2000). We use the definition of the Arctic Front (a distinctive feature of the Nordic seas separating true surface AW masses from mixed Arctic waters) to infer that the E/C ratio (ie. deviations from its “1” value) characterizes surface sediments deposited below AW or ArW surface water masses. We however agree on the fact this assumption might be less strict under certain circumstances: this is the case during late summer periods when the Arctic Front loses its boundary function (ie. reduced gradients in temperature and salinity, extreme westward extension of AW influence), and when *E. huxleyi* might occur in high cell densities (Baumann et al., 2000) in close proximity to the East Greenland Current. This finding is backed up by our own observations (Dylmer et al., in prep) in surface water transects across the Nordic Seas. We will modify accordingly Chapter 3.3 (“Rationale for the selection of species-specific coccolith proxies”) by modulating the significance of the E/C ratio in terms of proxy of the overall nature of the surface water masses (mainly on the ground of late summer conditions). Still, we consider this proxy to be reliable when considering mean average pluriannual conditions as indicated by sediment samples.

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An additional comment by both the editor and reviewer 2 concerns the application of the E/C ratio in the Barents Sea and Fram Strait. The original dataset by Baumann et al. (2000) indeed provided sparse data from the eastern Fram Strait and western Barents Sea areas (with only two samples located far in the eastern part of the Greenland Sea indicating a dominance of *C. pelagicus* over *E. huxleyi* coccoliths (E/C ratio <1). Our surface sediment samples (top of core HH11 off western Svalbard, and top of core JM09-KA11 off western Barents Sea), which are located beneath the influence of the WSC, however indicate the opposite situation (E/C >1). Such a pattern can be explained by the mean annual abundances of both species in extant populations within surface waters under the influence of the WSC, west of Bjornoeye (Baumann et al., 2000), as well as by our own observations (Dylmer et al., in prep) in surface water samples west of Svalbard during the high production summer period (Sept-October 2007 and July 2011), both indicating a dominance of *E. huxleyi* vs. *C. pelagicus*. Part of this comment will be added in the Chapter 3.3 (“Rationale for the selection of species-specific coccolith proxies”).

Related comment by Reviewer 2 on the Influence of the East Spitsbergen Current (ESC) and Persey Current (PC) on the coccolith distribution: Although the ESC and PC might influence the JM09-KA11-GC core location, we do not think that these currents have any strong influence on HH11-134-BC (within the main core of the WSC). Previous investigations indeed showed the cold ArW/PW of these currents to be restricted to the shelf area, contributing to a strongly developed Arctic Front near the shelf edge (Salorenta et al., 2001). Hence the mere influence of the ESC and PC in our study area in terms of salinity, temperature and sea-ice is limited to the north western Barents sea area, in vicinity to the Kveithola trough where core JM09-KA11-GC is located.

Comment by J. Knies on “Does the presence of 40%subpolar foraminifera in the Fram Strait record justify a dominance of "Arctic waters" in the Fram Strait core”: An earlier study of living planktonic foraminiferal assemblages on a transect across Fram Strait

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(Carstens et al., 1997) has shown that foraminifera tend to thrive within the Atlantic water masses under both sea-ice and polar surface waters. This observation was followed by Spielhagen et al., 2011; Science) when interpreting their foraminiferal record and inferring that the presence of AW in this area during the RWP, and the MCA, with ca. 40% of total subpolar foraminifera, although reflecting an enhanced flow of AW, was of much lower magnitude than the modern (post 1900 CE) situation. Accordingly, Müller et al. (2012, QSR) argue for sustained sea-ice occurrences over our Fram Strait coring site throughout the last 3000 years (though not recording the modern period) based on phytoplankton biomarkers. Reference to both late works are given in chapters 4.3.1 and 4.3.2 of our manuscript. We will add a reference to Carstens et al. (1997) in the revised version.

Anonymous Referee n°2 expresses concern about the general idea of species drifting from 50 N to 80 N (*Gephyrocapsa muelleriae* and *Calcidiscus leptoporus*) and the fact that the same transport mechanism should occur for all other species (and not strictly the former two). Extensive works on the living coccolithophores in the Nordic Seas do not provide any firm evidence for the occurrence of *G. muelleriae* in the modern Nordic Seas : none of recent investigations ever recorded this species in surface water assemblages of various Nordic Seas setting (Baumann et al., 2000; Charalampopoulou et al., 2011; Dylmer et al., in prep). The only finding was provided by Samtleben and Schröder (1992) who identified *G. muelleriae* in two water samples collected in August September 1988 over the Vöring Plateau at 60 and 200 meters water depths. The recorded abundances are however excessively low (<300 coccolithophores /L) and does not confirm a modern production of *G. muelleriae* in the area (such low concentration are likely to be drifted from a southern origin). The grouping of *G. muelleriae* within a Norwegian-Sea group by Samtleben et al. (1995) is only based on this sole observation by Samtleben and Schröder (1992). Accordingly, distribution maps provided by Samtleben et al. (1995, their figures 3a and b) do not mention *G. muelleriae* in the list of species explaining the distributional maps. We do however acknowledge that *G. muelleriae* was described in sediment traps (though in very low abundance) in

the Norwegian and Greenland Seas (Andrulleit, 1997). However a striking feature is its near absence from shallower traps (ca. 500m) compared with deeper settings (3000 m), as well as its near continuous presence throughout the recorded years. Both results later lead Andrulleit and Baumann (1998) to suggest that *G. muelleriae* was probably drifting from outside the Nordic Seas according to the main current circulation of western Norway. Most of these information are provided in Giraudeau et al. (2010, QSR) when defining the *G. muelleriae* proxy in the Nordic Seas. Regarding the issue of other species drifting to the Northern sites, we obviously agree with reviewer 2 and do believe that drifting occurs for all species produced south of the Nordic seas. We however expect that in situ production of *E. huxleyi* and *C. pelagicus*, which are dominating the living coccolithophore community of the Nordic Seas, given its magnitude, is to a high extent dominating the fossil signal of both species.

Comment by reviewer 2 on “Advection of AW and fluctuations of the AF”:

The decreased (and not “increased” as stated by reviewer 2) E/C ratios at core MD95-2011 throughout the last 2000 years are definitely due to an increased abundance of *C. pelagicus*. A comparison with the alkenone surface temperature record obtained on the same core by Calvo et al. (2002) is indeed useful to confirm the interpretation of a stronger influence of surface ArW over the Vöring Plateau. We did refer to this work by Calvo in the initial version (bottom part of section 4.3.1) Based on the fact that the E/C ratio originates from the relative abundances of *E. huxleyi* and *C. pelagicus*, and that both species explain 80 to 90% of the total assemblages, we do not find necessary to address specifically the changes in the relative abundances of both species.

Reviewer 2 is concerned about the general comparison of the coccolith record (*G. muelleriae*) with NAO patterns and find the comparison a bit arbitrary. We fully understand this concern and admit that the comparison between the NAO index and the abundance of the inflow species should not be interpreted on a basis of a point-by-point comparison, but rather as overall similar trends. In addition, several biases might hamper a detailed comparison between both records, such as the inherent errors be-

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hind age models, the temporal resolution of the coccolith record, the spatial location of the pressure systems governing the NAO, errors in the NAO reconstructions, as well productivity changes of *G. muelleriae* in its southern native area. The JM09-KA11-GC core does not show a clear fit with the NAO index, however as mentioned above, the Kveithola trough is affected by other colder currents (PC and ESC), which most likely have an effect on the coccolith signal there. The changes observed at around 650 cal. yr BP (inflow proxy), at the onset of the LIA, is based on the MD95-2011 record, as this record is the best stratigraphically resolved core of the three presented. HH11-134-BC shows a sharp negative anomaly in *G. muelleriae* abundance at ca. 725 cal. yr BP, a date which we do not find unreasonable to compare with MD95-2011, as we did apply a standard $R=0$ reservoir correction to all studied cores. An average reservoir correction of 57 ± 13 based on a few data points around Svalbard (from Calib database), would certainly improve the comparison between both records. The implication of limited stratigraphical controls on the interpretation of our records will be shortly discussed toward the end of the discussion section of the revised manuscript.

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