



Particle sedimentation patterns in the eastern Fram Strait during 2000–2005: Results from the Arctic long-term observatory HAUSGARTEN

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ARTICLE INFO

Article history:

Received 2 March 2008

Received in revised form

27 April 2009

Accepted 28 April 2009

Available online 7 May 2009

Keywords:

Vertical particle flux

Inter-annual variability

Ice coverage

Species composition

Fram Strait

ABSTRACT

Since 2000 long-term measurements of vertical particle flux have been performed with moored sediment traps at the long-term observatory HAUSGARTEN in the eastern Fram Strait (79°N/4°E). The study area, which is seasonally covered with ice, is located in the confluence zone of the northward flowing warm saline Atlantic water with cold, low salinity water masses of Arctic origin. Current projections suggest that this area is particularly vulnerable to global warming. Total matter fluxes and components thereof (carbonate, particulate organic carbon and nitrogen, biogenic silica, biomarkers) revealed a bimodal seasonal pattern showing elevated sedimentation rates during May/June and August/September. Annual total matter flux (dry weight, DW) at ~300 m depth varied between 13 and 32 g m⁻² a⁻¹ during 2000 and 2005. Of this total flux 6–13% was due to CaCO₃, 4–21% to refractory particulate organic carbon (POC), and 3–8% to biogenic particulate silica (bPSi). The annual flux of all biogenic components together was almost constant during the period studied (8.5–8.8 g m⁻² a⁻¹), although this varied from 27% to 67% of the total annual flux. The fraction was lowest in a year characterized by the longest duration of ice coverage (91 and 70 days for the calendar year and summer season, May–September, respectively). Biomarker analyses revealed that organic matter originating from marine sources was present in excess of terrigenous material in the sedimented matter throughout most of the study period. Fluxes of recognizable phyto- and protozooplankton cells amounted up to 60 × 10⁶ m⁻² d⁻¹. Diatoms and coccolithophorids were the most abundant organisms. Diatoms, mainly pennate species, dominated during the first years of the investigation. A shift in the composition occurred during the last year when numbers of diatoms declined considerably, leading to a dominance of coccolithophorids. This was also reflected in a decrease in the sedimentation of bPSi. The sedimentation of biogenic matter, however, did not differ from the amount observed during the previous years. Among the larger organisms, pteropods at times contributed significantly to both the total matter and CaCO₃ fluxes.

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1. Introduction

The Arctic Ocean, one of the regions most sensitive to climatic changes, has received increasing attention recently because of the drastic decrease of sea ice cover and extent (e.g., Maslanik et al., 2007; Comiso et al., 2008). These changes in the physical environment will eventually have enormous consequences for the pelagic system, as well as for the export of organic matter from the productive layer to the deep sea (Thingstad et al., 2008). Knowledge of this export is fundamental to our understanding of the global carbon cycle. Long-term investigations are a prerequisite to our understanding of the concomitant changes in sea surface temperatures, in sea ice and in the pelagic realm.

The downward flux of particulate matter and the inter-annual and seasonal variability in the amount and composition of the particles can provide indirect insight into the pelagic system above. Sediment traps are the only particle collectors capable of measuring the direct downward flux of particles (Zeitzschel et al., 1978; Asper, 1987; Kremling et al., 1996). As far as we know, however, only a few long-term observations exist in the deep Arctic Ocean because of its inaccessibility and logistic constraints. Studies of particle flux for 1 year or longer have only been done on few occasions (Honjo, 1990; Hebbeln and Wefer, 1991; Hargrave et al., 1994; Zernova et al., 2000; Peinert et al., 2001; Michel et al., 2002; Fahl and Nöthig, 2007). Most other studies were restricted to subarctic or shelf areas (e.g., Takahashi et al., 2000; Wassmann et al., 2004). Long-term observations using sediment trap moorings can thus provide a better understanding of pelagic processes in times of the changing climate. They are particularly suited to following the changes in ecosystem structure over longer periods of time and to possibly predicting future trends and consequences, e.g. for carbon fluxes in the ocean.

The use of sediment traps and the validity of results obtained by these devices has been a matter of debate for more than 20 years over hydrodynamical biases and trapping efficiency (Butman, 1986; Gust et al. 1994; Gardner, 1999; Scholten et al., 2001). Buesseler et al. (2007) recently reviewed problems related to the use of sediment traps in the upper ocean. Despite the uncertainties specified in this review, which one has to bear in mind when dealing with sediment trap data, we are confident that sediment traps provide an appropriate tool to gain insights in downward particle flux patterns throughout the year. They are independent of shiptime and weather conditions, and at present, they are the only tools that allow the continuous collection of sinking particles for further analyses over longer periods of time.

Here we present the results from the first 5 years of investigation from the central station of the HAUSGARTEN deep-sea observatory. This long-term observatory, established by the Alfred-Wegener Institute for Polar and Marine Research (AWI) in 1999, is located in the eastern Fram Strait between 78°30' and 80°00'N and between 3° and 7°E, ca. 120 km west of Spitsbergen (Fig. 1). It comprises water depths from 5000 to 1300 m (for details see Soltwedel et al., 2005). Sediment traps have been

deployed 250–300 m below the water surface and 150 m above the sea floor every year since 2000. The longest time series on sedimentation was obtained from the uppermost traps, and thus we concentrate on these results to present seasonal and inter-annual changes in flux pattern and composition of settling matter.

In this study we use sediment traps as a remote sensing tool to gain insights into seasonal succession within the upper pelagic realm. This enables us to gain perspective on growing and resting phases as well as the respective particle fluxes of the pelagic system even in ice-covered or temporarily ice-covered environments. The results obtained during the first years of the study may also serve as a baseline against which to monitor expected changes in the pelagic environment in this vulnerable region of the ocean.

In general, the Arctic Ocean, including the HAUSGARTEN area, is less productive than other oceans because of the permanent icecover and the extreme seasonal variability of irradiation. Data presented in this manuscript are available in the database PANGAEA (<http://doi.pangaea.de/10.1594/PANGAEA.714845>).

2. Hydrographic regime at the HAUSGARTEN

The particle flux in this region is influenced by sea ice and hydrographic conditions. In the eastern Fram Strait, warm and saline water of Atlantic origin is transported to the north with the West Spitsbergen Current (WSC), whereas in the western Fram Strait the East Greenland Current (EGC) carries less saline and cold polar water masses (PW) to the south in the upper layer. The Arctic Front (AF), separating the warm and cold water masses, is located within the investigation area at 4–6°E (Hop et al., 2006), thus involving the influence of both Atlantic and Polar water masses on the inhabiting organisms.

The northward flowing WSC has its core at the shelf slope off Spitsbergen. The Atlantic water (AW) masses are confined to the upper 700 m at the latitude of the sediment trap moorings. The strength of the AW inflow varies with the seasons, inter-annually and over longer time periods. Long-term fluctuations may be related to the North Atlantic Oscillation (NAO) (e.g., Saloranta and Haugan, 2001, 2004; Schauer et al., 2004), which also correlates well with variations in the sea ice extent in the Nordic Seas (Vinje, 2001; Divine and Dick, 2006).

Local circulation patterns and hydrographic conditions were inferred from long-term measurements at a moored array at 78°50'N (for details see Fahrbach et al., 2001; Schauer et al., 2004, 2008). Even though the line of moorings is located ca. 20 km to the south of the position of the sediment traps, the mean currents observed there are representative for the flow pattern in the area.

The complex bathymetry including a system of ridges, deeps and seamounts (Fig. 1) strongly affects the currents in the area. A part of the inflowing AW recirculates immediately in the Fram Strait along different pathways, because of the strong topographic steering (Bourke et al., 1987; Gascard et al., 1995; Walczowski et al., 2005). This

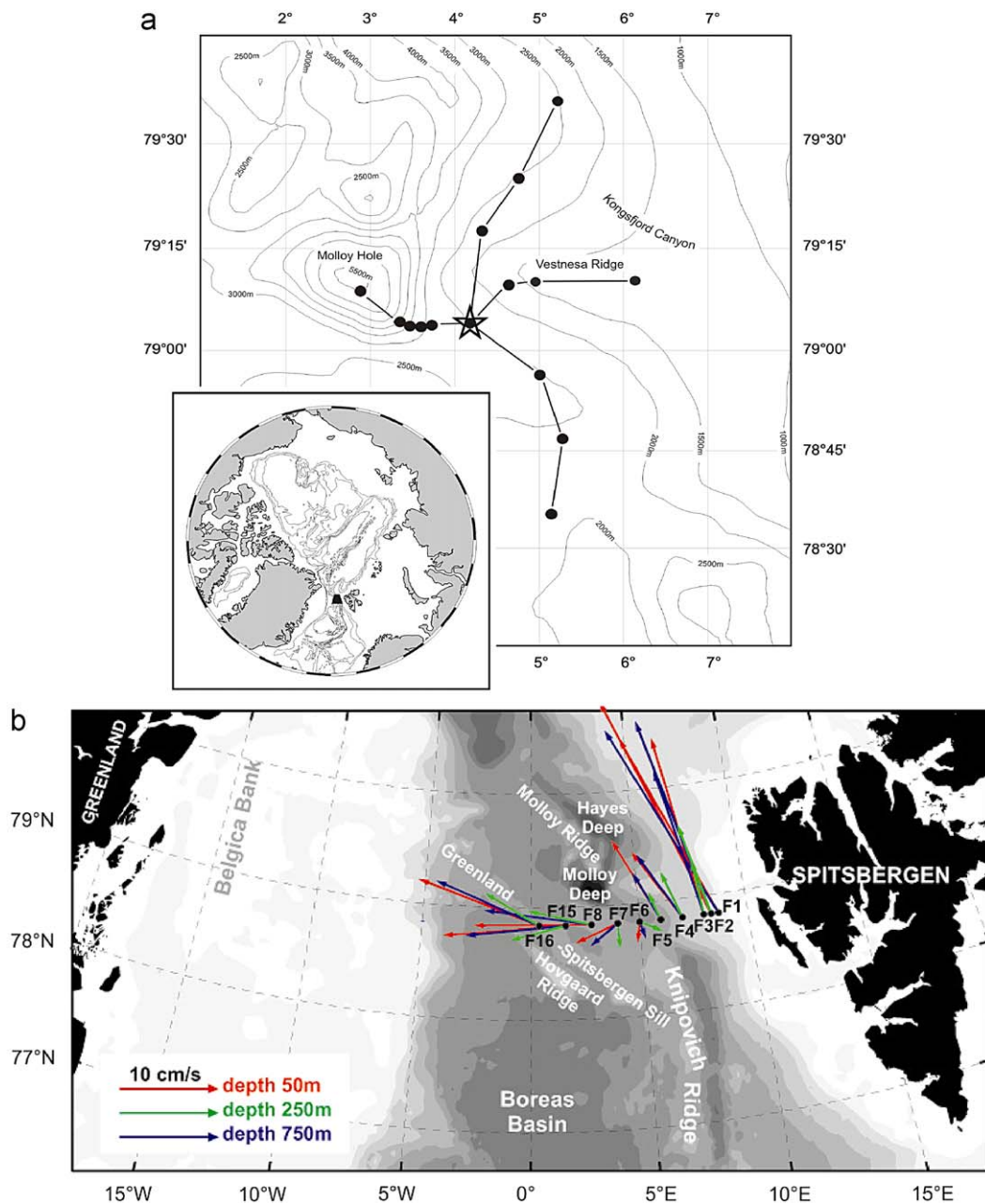


Fig. 1. Area of investigation in the eastern Fram Strait. (a) Station locations sampled regularly in the HAUSGARTEN; the star marks the position of the sediment trap mooring at the central station, (b) positions of oceanographic moorings at 78°50' N and mean currents in the upper layer in the Atlantic water for the period 2002–2006.

recirculating AW may also bring polar water and ice to the south and east, and thus over the sediment trap moorings.

The location of the ice edge in the eastern Fram Strait is strongly controlled by wind and the advection of the warm Atlantic water. The latter provides heat, which is necessary to melt ice, from the south. It also keeps the eastern part of the strait ice free for most of time. The melt water front is coupled to the position of the ice edge. When transported offshore under strong northerly winds the shelf water may also reach the eastern part of the

observatory. This shelf water is a mixture of the cold Arctic water carried within the coastal current around Svalbard, the Atlantic water advected to the shelf, and the outflow from fjords.

The mean currents observed in 2002–2006 at the moored array at 78°50' suggest that the eastern part of the area is affected primarily by AW carried along by the offshore part of the WSC. This branch is slower than the core of the WSC and meanders considerably. The observed flow pattern (Fig. 1) supports the presence of a cyclonic

gyre related to the bottom topography (Quadfasel et al., 1987).

Hydrographic and biological conditions at the investigation area are influenced by sea ice melting. Two warming periods were observed in Fram Strait in 1998–1999 and 2003–2006 (Schauer et al., 2008). The latter was also pronounced in the recirculating Atlantic water. In the northern Fram Strait the bottom of the ice also melts during winter time from the heat supplied by the westward recirculation of AW (Vinje et al., 2002). Increased temperatures of the AW (particularly in winter) and an increased heat advection enhanced the ice melting and resulted in a shift of the ice edge position in the studied area in recent years.

The amount of ice and subsequently of melt water in the northern Fram Strait is also affected by the seasonal changes in the wind field. Easterly wintertime winds feed the northern Fram Strait with thinner ice from the southern part of the Eurasian Basin, whereas northerly summertime winds supply thicker ice from Greenland to the ice drift core (Vinje et al., 1998).

3. Methods

3.1. Particle flux collection

Sedimenting particles were sampled by modified automatic Kiel sediment traps, with a sampling area of $\sim 0.5 \text{ m}^2$, and 20 liquid-tight collector cups (Zeitsschel et al., 1978; Kremling et al., 1996). The sediment traps were installed in bottom-tethered, long-term moorings at different depths. Here, we present results from the shallowest sediment traps (~ 250 – 300 m below the water surface), as we obtained the longest time series from this layer compared with one complete annual cycle only from the deep traps during 2000–2005. Details for the respective moorings are compiled in Table 1. There was a gap of data between 2003 and 2004 due to technical failures of the trap electronics.

The traps were programmed to collect in high resolution (7–17 days) during the productive summer season (May–September) and in longer intervals (up to 2 months) during the winter. The collector cups were filled with filtered sterile North Sea water, which was spiked with NaCl to adjust the salinity to 40. The liquid in the collector cups was poisoned with mercury chloride (0.14% final solution). After recovery of the moorings the samples were stored refrigerated till further processing in the

laboratory. Samples were split by a wet splitting procedure as described by von Bodungen et al. (1991).

Before splitting of the samples swimmers $>0.5 \text{ mm}$ were manually removed under a dissecting microscope at a magnification of 20 and 50. Organisms (e.g., Amphipoda, Copepoda, Pteropoda, Chaetognatha) were sorted, enumerated and refrigerated in storage.

3.2. Analyses of flux components

Sub-samples of the remaining material were filtered for the subsequent analyses of total sedimented matter (dry weight, DW), particulate organic carbon and nitrogen (POC/N), calcium carbonate (CaCO_3), and biogenic particulate silicon (bPSi). Analyses of bulk components were performed as described by von Bodungen et al. (1991). One split of each collector cup (1/8) was used for biomarker analyses.

The total flux and the flux of CaCO_3 were corrected for the contribution of pteropods, which were present in greater numbers at certain periods. The corrections were done by applying a factor of 0.174 mg/ind for DW and 0.167 mg/ind for carbonate (Bauerfeind, unpubl. data). These factors were used for empty pteropod shells only, as these probably sank passively. For this reason and because only pteropods $>0.5 \text{ mm}$ were removed from the samples and because varying amounts of broken pteropod shells were observed, the calculated contribution of pteropods to vertical particle flux has to be regarded as a minimum.

In the collector cups, substantial portions of the accumulated particulate matter can dissolve during the mooring period and during the storage time of the samples (Noji et al., 1999a; Kähler and Bauerfeind, 2001; Bauerfeind and von Bodungen, 2006). The data presented (namely POC/N and bPSi) therefore represent the refractory fraction only and are an underestimate, as the quantity of dissolved material was not determined.

The fraction of biogenic matter was estimated according to Fischer et al. (1996): Biogenic matter = $2 \times \text{POC} + \text{CaCO}_3$ Opal (Opal = $2.1 \times \text{bPSi}$). The difference between total flux and biogenic matter flux is a measure of the flux of the lithogenic fraction (Lithogenic = DW – Biogenic).

To determine the contribution of inorganic carbon flux, particulate inorganic carbon (PIC) was calculated as 12% of carbonate content. Where possible, annual fluxes were calculated from the individual values. In cases of shorter gaps between successive sampling periods values were interpolated from the preceding and succeeding mooring

Table 1
Details of sediment trap moorings in the “AWI-HAUSGARTEN”.

Mooring period	Lat. N	Long E	Water depth	Trap depths	Start	End	No of samples
31.08.2000–14.08.2001	79°01.7'	4°20.86'	2456	280	31.08.2000	14.07.2001	18
14.08.2001–29.07.2002	79°01.5'	4°21.30'	2482	260	14.08.2001	14.03.2002	11
14.08.2002–10.06.2003	79°01.04'	4°19.77'	2593	260	14.08.2002	10.06.2003	20
25.03.2003–14.07.2003	78°59.95'	4°27.44'	2568	340	25.04.2003	25.07.2003	20
01.08.2003–15.06.2004	79°01.00'	4°19.99'	2597	280	no data		none
12.07.2004–19.08.2005	79°00.99'	4°20.62'	2584	300	15.07.2004	30.06.2005	18

period. To fill the gap in the data during June/July 2003, we used data from a sediment trap deployment at 340 m depth from March to July 2003 in the vicinity of the long-term mooring (Table 1).

3.2.1. Biomarkers

To gain better insights into the biochemical composition of the particulate organic matter-specific sterols were investigated. In order to get information on the proportion of marine organic carbon we use the diatom-specific sterol 24-methylcholesta-5,22-E-dien-3 β -ol (brassicasterol) (Robinson et al., 1984; Yunker et al., 1995). To estimate the relevance of “terrestrial input” campesterol (24-methylcholest-5-en-3 β -ol) and β -sitosterol (24-ethylcholest-5-en-3 β -ol), synthesized by higher plants (e.g., Huang and Meinschein, 1976; Volkman, 1984), were used.

For analyses the samples were extracted, transesterified, and separated into fractions by column chromatography. The sterol fraction was silylated with bis-trimethylsilyl-trifluoroacetamide (BSTFA) and analyzed by gas chromatography/mass spectrometry. For quantification cholest-5-en-3 β -ol-2,2,3,4,4,6-d₆ was added as internal standard before any extraction and analytical step. For further details see Fahl et al. (2003).

3.2.2. Microscopy

Quantitative microscopic analysis was carried out by inverted microscopy of sub-samples of the intercepted material. Aliquots of the settled material were used to enumerate sedimented phytoplankton and protozooplankton (Utermöhl, 1958). A minimum of 50–100 cells of the dominant species or groups were counted at four different magnifications (100, 160, 250, and 400 \times) using phase contrast microscopy. Here, we only present cell counts for dominant species or groups that were easily distinguished (mainly shell-bearing organisms) in the samples. Thus, analyses focused primarily on free coccolithophorids, diatoms, and tintinnids. The occurrence of foraminiferans, radiolarians, faecal material and detritus was noted. Coccoliths were also enumerated in some of the samples; however, as this was not done consistently for all of the samples the results are not considered here. An estimation of the contribution of coccoliths to carbonate flux using factors reported by Young and Ziveri (2000) revealed that its contribution was minor (\sim 1% or less).

Amongst the counted particles a small portion could not be assigned to a certain group. The sum of the counted objects are termed ‘total cells’, and identifiable objects were subsumed as recognizable cells, which accounted for more than 90% of the total cell sedimentation rate during all sampling years.

3.3. Remote sensing of ice

Ice concentrations in the area and the distance of the mooring position to the ice edge (ice concentration <15%) were obtained by analysis of satellite-derived special sensor microwave imager (SSM/I) data provided by the

National Snow and Ice Data Centre, (NSIDC), Boulder, Colorado).

For the analysis the 85 GHz SSM/I data and the ARTIST Sea Ice (ASI) algorithm were used, yielding an aerial resolution of 12.5 \times 12.5 km (Kaleschke et al., 2001; Kern et al., 2003). For consolidation of the inter-annual variation in ice conditions during recent years the analysis was extended back to the year 1996. The ice parameters and distances to the mooring positions were determined on a daily basis over this 10-year period.

3.4. Progressive vector diagrams with temperature (PVD-T)

The analyzed data originate from current meter measurements at a nominal depth of 250 m at the mooring F6, located \sim 20 km south of the sediment trap moorings during the period of the study (Fig. 1b). The Eulerian measurements of currents at the mooring location were displayed in the Lagrangian way of following the movement of water parcels (Fig. 6) separately for each 1-year, winter-centered deployment period. The progressive vector diagrams show how the water parcel would have moved if the current had been the same no matter where the particle moved to. The temperature of water carried by the current is color-coded. The PVD-T diagrams indicate also the geographical orientation of the statistical collection funnel of the sediment traps (Siegel and Deuser, 1997).

4. Results

4.1. Ice conditions

Sea ice may drift into the HAUSGARTEN area from three directions: the region north of Spitsbergen, the western Fram Strait, and on rare occasions also from the Spitsbergen shelf in the east. However, analyses of the ice data showed that the mooring position is predominantly influenced by ice from the west. This ice is drifting out of the central Arctic Ocean and is transported southwards with the East Greenland Current (EGC). Seasonal variations and alterations on shorter time scales are recognizable within the observation period (Fig. 2a). There are longer periods with no ice in the vicinity of the moorings (e.g. the years 1999/2000, and 2004). The greatest distances of the ice edge from the trap positions were \sim 300 km and the widest extensions beyond the mooring position reached \sim 75 km. Ice was not observed at the mooring site only during winter. During summer, the mooring position was also regularly covered by ice or located close to the ice edge (Fig. 2a and b).

Periods of ice coverage for the calendar year ranged between 91 days in 2003 and the total absence of ice in 1999 (Fig. 2b). During the summer the prevalence of ice varied between 70 days in 2003 and the complete absence in 1999 and 2004. In the years 1998, 2000 and 2003 ice was present mainly during the summer (Fig. 2a and b). The mean duration of ice presence at the mooring site was 36 and 22 days for the calendar year and the summer season, respectively. Significance of deviation from the

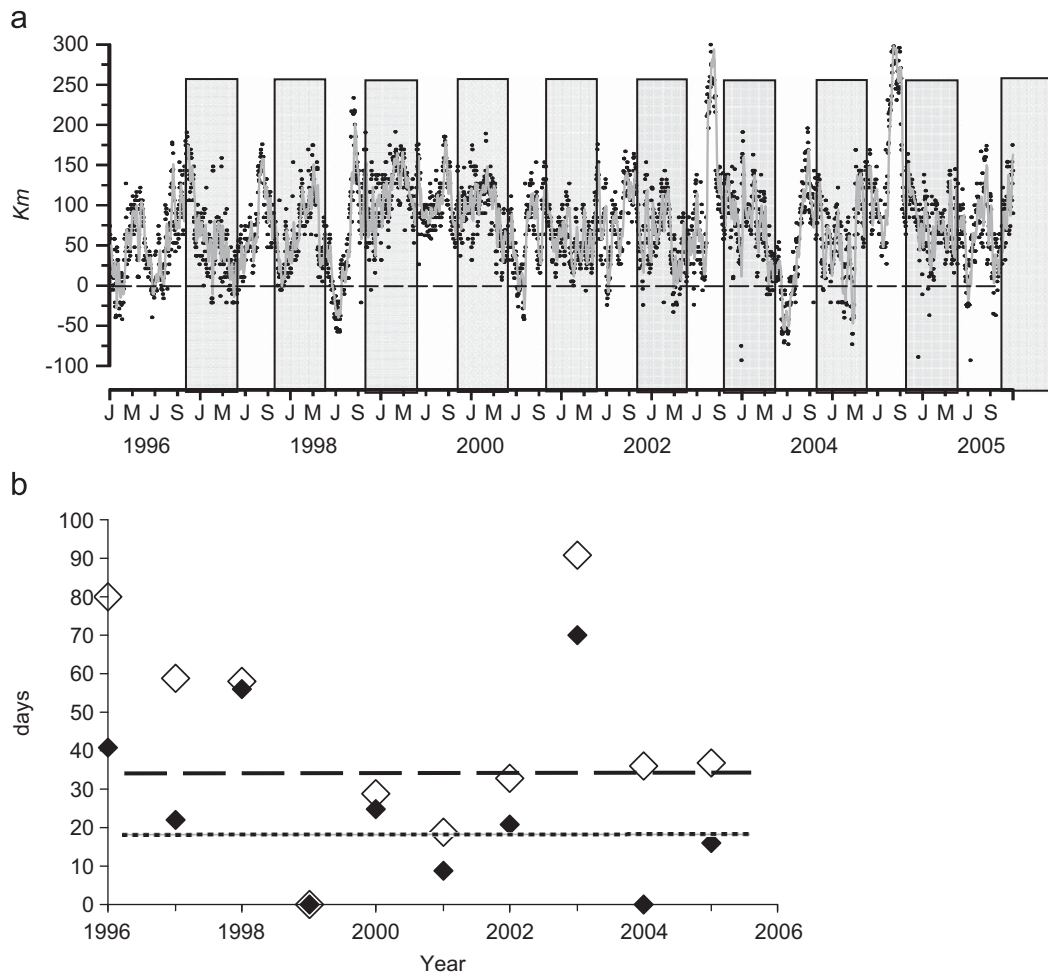


Fig. 2. (a) Distance of the ice edge (km) from the mooring position at 79°N/4°E for the period 1996–2005 (dots: daily measurements; solid line: 7-day running mean); distances are negative when the mooring was covered by ice and the ice edge was located to the east of the mooring; dashed line marks the ice edge position at the mooring site. Shaded areas mark the winter period (October–April), (b) duration of ice coverage (days) for the calendar years (open symbol) and during the summer period (closed symbol); long dashed line and dotted line mark the medians for the whole year and for the summer season, respectively.

medians was tested with the one sample sign test (Data Desk®). Periods of ice coverage were significantly different in the years 1996, 1999, 2001, 2003 for the calendar year and in 1999, 2003, and 2004 for the summer period, respectively. No trends in the duration of ice coverage at the mooring site were found within the observation period. Ice concentrations varied from 15% to 60%, and concentrations >60% were only rarely encountered.

4.2. Total flux and components

Fig. 3 illustrates the sedimentation rates of total matter (DW) and its components in combination with the distance of the ice edge to the mooring positions. Total flux varied between 4 and 506 mg m⁻² d⁻¹ showing distinct seasonal variations with minimum fluxes during winter. The total flux regularly increased during March/

April, and, with the exception of the year 2003, was at maximum during August/September. In 2002/2003 elevated fluxes were measured in the period March–June 2003 with the overall maximum of 506 mg m⁻² d⁻¹ during April/May (Fig. 3b).

The seasonal pattern of calcium carbonate (CaCO₃) sedimentation paralleled the pattern of total flux, with the exception of the period 2002/2003, when carbonate flux remained moderate (~5–10 mg m⁻² d⁻¹) also during the times of increased total flux. Largest fluxes of this component amounted to ~50 mg m⁻² d⁻¹ (40–68% of total flux) during periods of the peak fluxes.

Carbonate shell-bearing pteropods contributed significantly to the total matter flux and the flux of carbonate intermittently (Fig. 3b), but with large inter-annual variability. Maximum fluxes of 150–250 shells m⁻² d⁻¹ were observed at the end of the year during September–December in 2000 and 2004. In other years, the maximum fluxes were ~100 organisms m⁻² d⁻¹. No pteropods, or

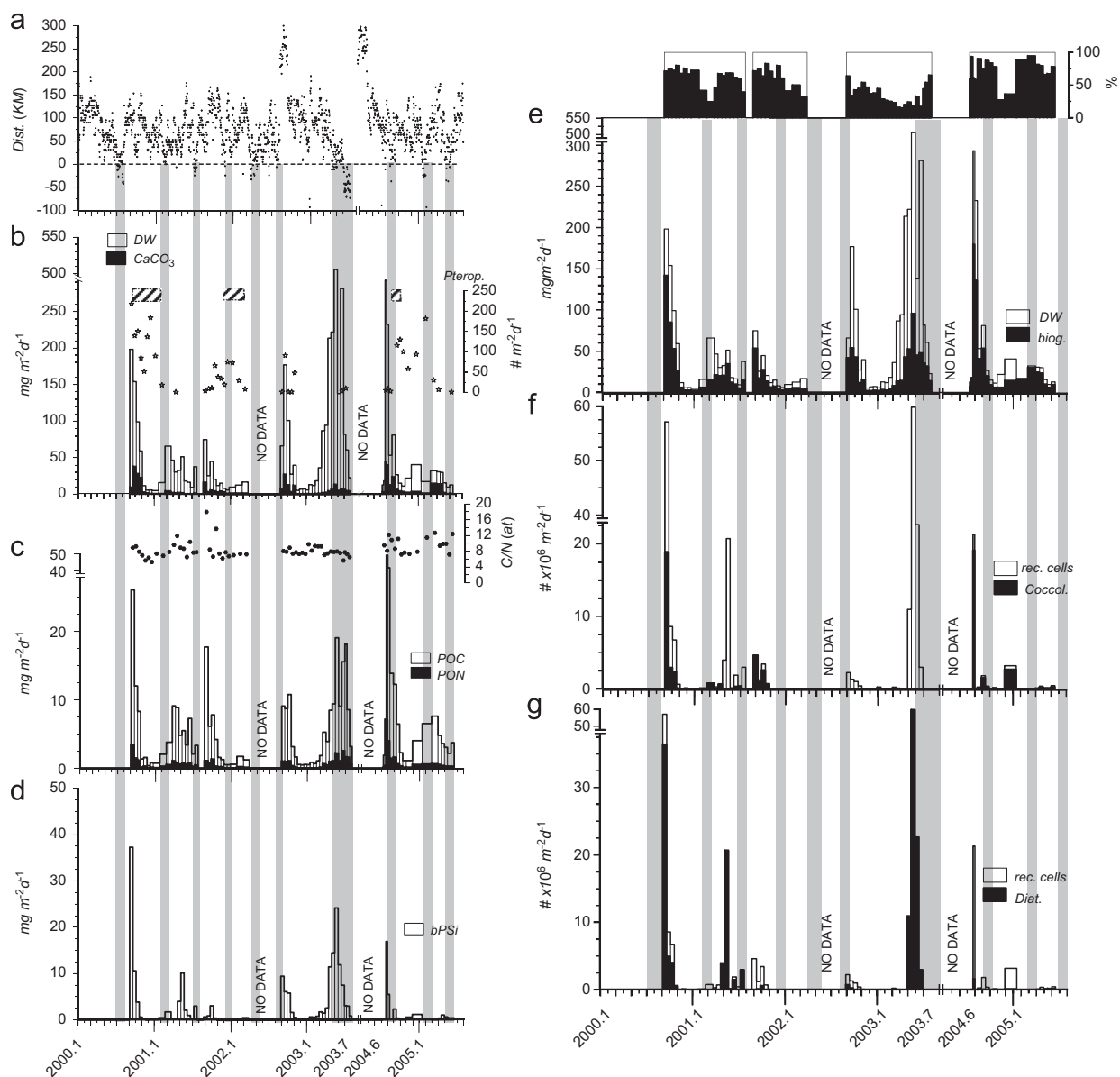


Fig. 3. Distance (km) of ice edge from mooring position at 79°N/4°E (a) and sedimentation observed at the AWI long-term observatory in the period 2000–2005. Fluxes (except pteropods) are presented in $\text{mg m}^{-2} \text{d}^{-1}$. (b) Total flux (DW), flux of calcium carbonate (CaCO_3) and number of pteropods (striped bars indicate periods when *Limacina retroversa* was observed in larger quantities or were dominant), (c) flux of particulate organic carbon and nitrogen (POC/N) and C/N ratio, (d) biogenic particulate silica (bPSi), (e) total flux and biogenic matter flux; the upper panel represents the proportion of biogenic matter on total flux, (f) sedimentation of recognizable particles and coccolithophorids, (g) diatoms. Shaded vertical bars indicate periods when the location of the moorings was covered by ice or was located within ± 12.5 km of the ice edge.

only very few specimens were usually observed during summer. Most pteropods observed belonged to *Limacina helicina*. However, during some periods also an abundance or even a dominance of *Limacina retroversa* was observed (Fig. 3b). In the periods of maximum pteropod fluxes, both *Limacina* species contributed 15–35% and 50–90% to total matter and CaCO_3 sedimentation, respectively.

The flux of particulate organic carbon and nitrogen (POC and PON) generally followed the pattern of total matter flux. During the periods of elevated sedimentation from August to October (Fig. 3c) flux of POC was ca.

25–45 $\text{mg m}^{-2} \text{d}^{-1}$ and, flux of PON was 2.5–7.5 $\text{mg m}^{-2} \text{d}^{-1}$. Although in spring and early summer 2003 a considerable increase in organic C and N sedimentation was observed, fluxes of these components did not show the same jump as observed for total matter sedimentation.

Ratios of POC/PON (C/N) generally varied between 5.2 and 13.7 in most samples. Only a few samples yielded larger values (Fig. 3c). While little variation in C/N ratios was observed in 2002/2003, considerable variations were found during the course of the year during the other mooring periods.

Fluxes of biogenic particulate silica (bPSi) were in a similar range as the organic carbon fluxes, with maximum sedimentation rates of 30 and $38 \text{ mg m}^{-2} \text{ d}^{-1}$ during September 2000 and May/June 2003, respectively (Fig. 3d). Slight increases from the very low sedimentation rates during winter ($<1 \text{ mg m}^{-2} \text{ d}^{-1}$) occurred every year in the period April–June. During almost the whole mooring period 2004/2005, however, bPSi sedimentation rates stayed at a noticeable low level.

Biogenic matter sedimentation co-varied with the flux of total matter and ranged between 60 and $180 \text{ mg m}^{-2} \text{ d}^{-1}$ during the periods of elevated particle flux (Fig. 3e). Lowest fluxes recorded during winter were $\sim 10 \text{ mg m}^{-2} \text{ d}^{-1}$. Apart from the winter season, the flux of biogenic matter accounted for more than 50% of the total matter sedimentation during almost every year. However, this was different in 2002/2003, when the share of this component rarely exceeded 50%. It was 25% or less during the period exhibiting maximum total matter flux, when lithogenic matter clearly dominated.

4.3. Microscopic composition

Diatoms, diatom spores, coccolithophorids and tintinnid shells were the main organisms identified in the samples. Occasionally also silicoflagellates and dinoflagellates were present. Diatoms and coccolithophorids were the most abundant organisms. At times, these clearly dominated the flux of recognizable cells, which amounted as much as $60 \times 10^6 \text{ cells m}^{-2} \text{ d}^{-1}$ (Fig. 3f and g). Diatoms dominated during the periods of highest fluxes in September/October 2000 and May/June 2003 as well as in April/May 2001. During the latter period, however, the flux was $\sim 20 \times 10^6 \text{ m}^{-2} \text{ d}^{-1}$ and represented only \sim one third of the overall maximum flux of the period 2000–2005. Within the last mooring period in 2004/2005, numbers of recognizable cells in the trap samples were very low with $<5 \times 10^6 \text{ cells m}^{-2} \text{ d}^{-1}$. Only in August 2004 were fluxes of $\sim 20 \times 10^6 \text{ cells m}^{-2} \text{ d}^{-1}$ encountered. Diatoms contributed little to the flux of recognizable cells during the entire period, and they were clearly outnumbered by coccolithophorids. No increase in flux was observed in spring and early summer 2005, and this seasonal pattern differed distinctly from the pattern observed during the years 2000–2003 (Fig. 3f and g).

In addition to these objects which were distinguishable by microscopy, varying quantities of unidentifiable matter, mainly consisting of detritus, were observed in the samples. This was particularly true for the last mooring period. During its high flux period in August/September 2004 objects could therefore not be properly counted in some samples.

4.4. Dominant organisms

4.4.1. Diatoms

Diatoms regularly showed two peaks in flux over the course of the year, one at the end of the growth season

during August–mid-September and another one in spring from the end of April–early-June. Centric diatoms prevailed in autumn, whereas pennate diatoms dominated in the samples during spring. The amount of diatom frustules in the collected material during autumn 2001, 2002/2003, and the entire sampling period 2004/2005 generally was about an order of magnitude lower than in 2000/2001 (autumn and spring). Largest sedimentation rates of diatoms, particularly pennate forms, were observed from the end of April to the beginning of May 2003. *Fragilariopsis* spp. (mainly *F. cylindrus*) accounted for 76% of total diatom flux during that period (Table 2). Occasionally the flux of diatoms was dominated by the centric diatoms *Chaetoceros* spp., mainly as resting spores, *Thalassiosira* spp. and the ice-associated pennate diatoms *Fragilariopsis* spp., *Navicula* spp. and *Nitzschia* spp.. Only in fall and early winter 2004 did *Rhizosolenia* spp. amount to $\sim 40\%$ of total diatom flux rates. During all other years the contribution of this species was $\leq 11\%$ (Table 2). Sedimentation patterns of *Chaetoceros* spp. and *Thalassiosira* spp. were similar during all sampling periods; however, their numbers were fairly low during 2004–2005.

4.4.2. Coccolithophorids

Two species of coccolithophorids could be distinguished in the samples: *Emiliania huxleyi* and *Coccolithus pelagicus*. Both showed higher abundances in the sedimented material mainly in late summer and autumn. However, the sedimentation rates of the much smaller *E. huxleyi* cells exceeded by far (factor 1000) those of *C. pelagicus* during the periods of maximum coccolithophorid sedimentation. *C. pelagicus* only occasionally contributed considerably to or dominated the sedimentation of coccolithophorids (Table 2).

4.4.3. Other organisms

Tintinnids were the most prominent heterotrophic protists in the sedimented material. They also showed a distinct sedimentation pattern during the season. Highest fluxes were reached in August and September dominated by *Parafavella denticula* and *Acanthostomella* c.f. *norvegica*. Other protists, like acantharia, foraminifera, and radiolaria, were present in much lower numbers than the tintinnids (factors 10–100), but were regularly observed during the period of our investigation.

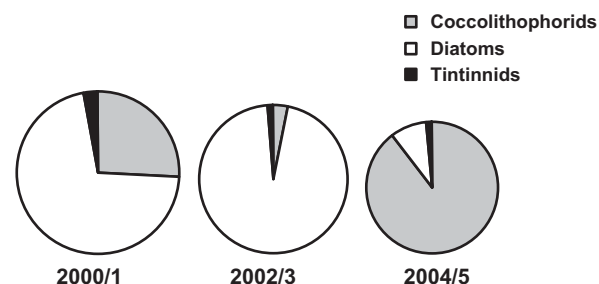
The relative contribution of the dominant protist groups in the flux of recognizable cells integrated for the respective mooring periods (Fig. 4) reveals a clear dominance of diatoms within the periods 2000–2003, whereas during the sampling period 2004/2005, coccolithophorids dominated. However, the numbers of recognizable cells decreased in the latter period and amounted to $\sim 1/3$ of the amount observed in the two preceding mooring periods. This most notably is due to a considerable decrease in the occurrence of diatom frustules. The relative contribution of tintinnids in sedimentation of recognizable cells was more or less constant during the period of observation.

Table 2

Most abundant phytoplankton observed in the sediment trap samples.

Period	% of coccolithophorids		% of dominant diatoms				
	<i>Emiliana huxleyi</i>	<i>Coccolithus pelagicus</i>	<i>Thalassiosira</i> spp.	<i>Chaetoceros</i> spp.	<i>Rhizosolenia</i> spp.	<i>Fragilariopsis</i> spp.	Other Pennates
2000–2001							
Fall	99	1	31	48	2	0	19
Winter	94	6	83	0	6	0	11
Spring	80	20	25	16	0	28	31
Summer	59	41	28	33	0	15	24
2001							
Fall	99	<1	1	83	0	16	0
Winter	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Spring	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Summer	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
2002–2003							
Fall	85	15	5	83	11	1	0
Winter	31	69	100	0	0	0	0
Spring	99	<1	20	3	0	76	1
Summer	n.o.	n.o.	22	35	0	37	6
2004–2005							
Fall	96	4	30	8	44	5	13
Winter	98	2	2	6	39	4	49
Spring	97	3	26	32	0	27	15
Summer	99	<1	43	31	5	7	14

n.d.: no data, n.o.: not observed.

**Fig. 4.** Relative composition within the pool of recognizable cells for the period 2000–2005. The size of the individual graphs illustrates the amount of recognizable cells integrated over the respective mooring period.

4.5. Biomarkers

Biomarkers are used here to distinguish between marine and terrigenous organic carbon in the sediment traps. A more detailed analysis of biomarker composition will be published elsewhere. The fluxes of the marine and terrigenous sterols co-varied with the flux of total matter and generally exhibited a similar seasonal pattern as the other investigated constituents. Maximum fluxes varied between ~ 10 and $90 \mu\text{g m}^{-2} \text{d}^{-1}$ during most of the time for marine and terrigenous sterols, respectively (Fig. 5).

During a short period in August/September 2004 and September 2000, however, fluxes exceeding these values were measured (Fig. 5a and b).

The terrigenous sterols (campesterol and β -sitosterol) exhibited maximum flux rates at the beginning of the

study during September 2000. In periods of low total flux during winter these sterols were also detected in low concentrations (up to $\sim 2 \mu\text{g m}^{-2} \text{d}^{-1}$). An indication of the relevance of terrestrial or marine derived organic carbon can be shown by the ratio of terrigenous to marine sterols (Fig. 5c). Values of <1 predominated (Fig. 5c) and clearly indicate the importance of particles of marine origin. During short periods in 2000/2001 as well as during almost the entire winter period 2002/2003 sterols originating from higher plants and therefore indicating a terrigenous source dominated.

4.6. Annual sedimentation

The variations of the annual fluxes were astoundingly low for most of the measured components (Table 3). Exceptions from this were the sedimentation of total matter and bPSi. The latter exhibited a pronounced decrease during the period 2004/2005. The amount of total matter flux in 2002/2003 was approximately twice the flux measured during the other mooring periods. The contribution of pteropods to annual carbonate flux varied between 17% and 48%, but pteropods contributed less to total matter and biogenic matter flux (1–9% and 4–6%, respectively). The share of biogenic matter in total flux was $>50\%$ in 2000/2001 and 2004/2005. During the period of largest total matter flux in 2002/2003 biogenic matter had a share of only 27% in DW, and lithogenic matter clearly dominated the annual particle flux. The flux of all components during the summer period (May–September) contributed $>50\%$ of annual flux, and most of the biogenic components obviously sedimented

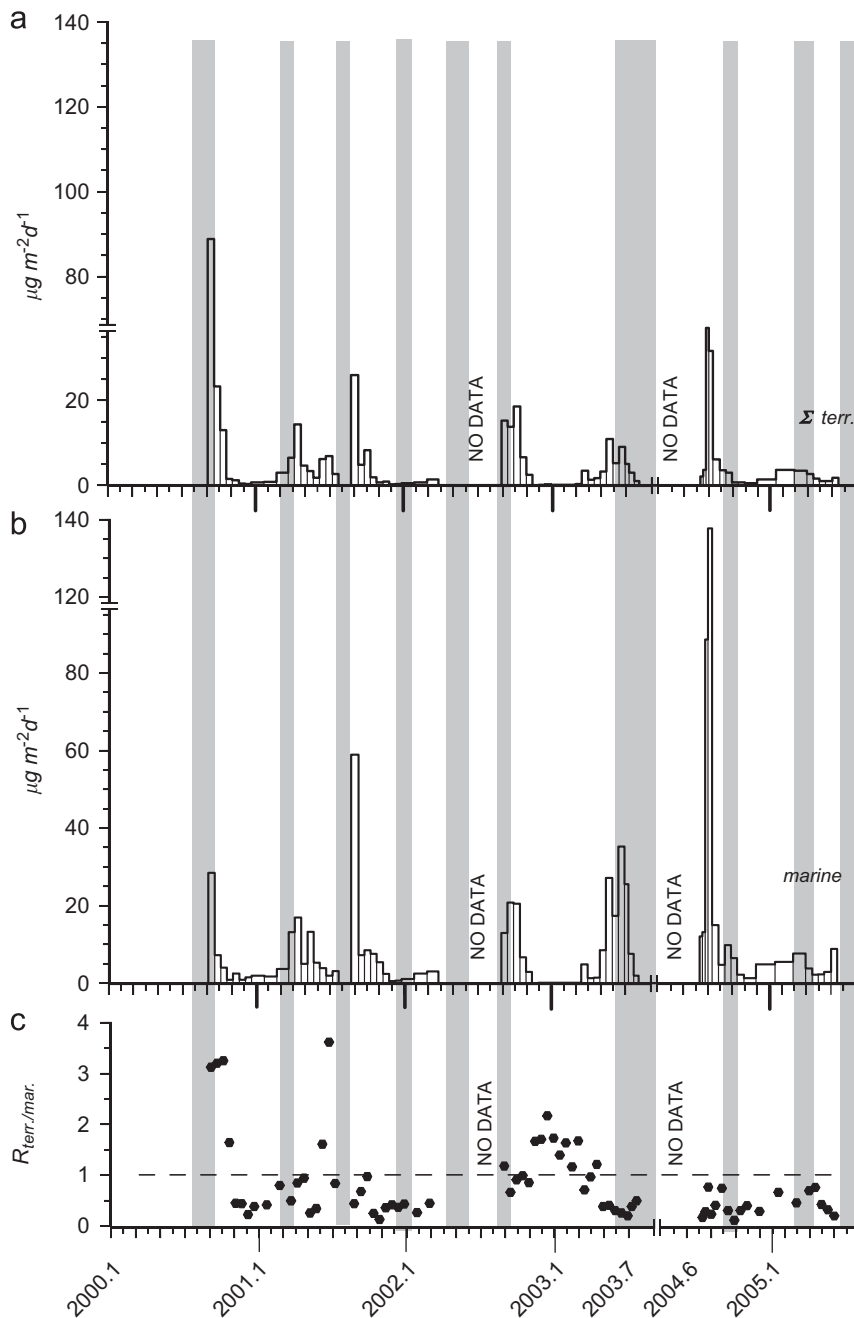


Fig. 5. Fluxes ($\mu\text{g m}^{-2}\text{d}^{-1}$) of sterols, (a) terrigenous (Σ Campesterol and β -Sitosterol), (b) marine (Brassicasterol) matter, (c) relation of terrigenous marine matter. Shaded vertical bars indicate periods when the location of the moorings was covered by ice or was located within ± 12.5 km of the ice edge.

during summer, although considerable inter-annual variations were present (Table 3).

5. Discussion

In the HAUSGARTEN area, we regularly noticed an increase in the sedimentation of biogenic components at ~ 300 m early in the growth season i.e., around April/May

(Fig. 3). From this pattern in sedimentation we deduce the onset of pelagic production in the preceding weeks. An early beginning of pelagic primary production in the growth season is supported by increasing chlorophyll concentrations as observed by remote sensing (SEAWIFS). Although these measurements are rare in the area during this part of the year concentrations of $\sim 1\text{--}2\text{ mg m}^{-3}$ chlorophyll during April/May are indicated in the scenes available from the region (<http://disc.gsfc.nasa.gov/oceancolor/>). Chlorophyll

Table 3

Annual sedimentation (g m^{-2}) and sedimentation during summer (May–September) of total matter (DW), calcium carbonate (CaCO_3), particulate organic carbon and nitrogen (POC/N), ratio of particulate organic carbon to particulates inorganic carbon (POC/PIC), biogenic particulate silica (bPSi) and biogenic matter (biogen); % gives the relative share of these components in annual total matter flux.

Period	DW	CaCO_3	%	POC	%	PON	%	POC/PIC	bPSi	%	Biogen	%
2000/2001	15.25 (9%)	2.57 (48%)	17	2.12	14	0.25	2	6.9	1.21	8	8.76 (6%)	57
Summer	9.23	1.34		1.40		0.15		10.3	1.01		5.85	
% summer	61	52		65		58			83		67	
2002/2003	32.09 (1%)	1.97 (18%)	6	1.58	4	0.25	1	6.7	1.67	5	8.54 (4%)	27
Summer	18.46	1.26		1.06		0.17		6.5	0.95		5.43	
% summer	57	64		67		68			60		64	
2004/2005	12.92 (5%)	3.01 (17%)	23	2.45	21	0.28	2	6.8	0.34	3	8.65 (6%)	67
Summer	7.3	1.58		1.53		0.17		8.0	0.24		5.16	
% summer	58	53		62		61			70		60	

Numbers in brackets depict the share of pteropods in flux of total matter, calcium carbonate and biogenic matter.

concentration within this range persisted till July and declined afterwards during August/September to $\sim 1 \text{ mg m}^{-3}$ or less when the production shuts down.

5.1. Seasonal flux pattern

The observed seasonal flux pattern in the eastern Fram Strait exhibiting a bimodal distribution with increasing fluxes during August/September and May/June is comparable to patterns and amounts of sedimented matter observed in the seasonally ice-covered regions of the Greenland Sea (Bauerfeind et al., 1994, 1997; Peinert et al., 2001). However, the amount of settling material as well as the flux pattern differs considerably from the results of a sediment trap study conducted in the late 1980s in the vicinity of the HAUSGARTEN moorings but closer ($\sim 120 \text{ km}$ to the southeast) to the Spitsbergen shelf (Hebbeln and Wefer, 1991; Hebbeln, 2000). At this location, the authors report a flux maximum during the winter period, and with up to $1150 \text{ mg m}^{-2} \text{ d}^{-1}$ and $117\text{--}230 \text{ g m}^{-2} \text{ a}^{-1}$, they also measured considerably larger daily and annual fluxes than we observed. These elevated fluxes during winter were attributed to sedimentation of ice-raftered detritus from the Svalbard region, released by melting of ice caused by the warm Atlantic surface waters in the area (Berner and Wefer, 1994; Hebbeln, 2000).

On the other hand, other sedimentation measurements across Fram Strait yielded moderate to low sedimentation rates, which were dependent on ice coverage and are comparable with the results reported here (Honjo, 1990; Berner and Wefer, 1994; Hebbeln and Wefer, 1991). In the year-round ice-free Greenland Sea at $75^\circ \text{N}/0^\circ \text{E}$, similar amounts of total matter and particulate organic matter sedimented (Noji et al., 1999b), but the seasonal flux pattern, exhibiting only one maximum in June–August clearly differed from the pattern we observed. Apparently, sedimentation in the Fram Strait region is spatially highly variable during the seasons. These flux variations in the amount, composition and seasonal pattern indicates the complexity of the oceanographic conditions. Especially the role of sea ice, but also variations in the efficacy of the biological carbon pump on seasonal time scales, which is

controlled by food web structure and dynamics (Peinert et al., 1989; Wassmann, 1998; Olli et al., 2002).

5.2. Export of organic carbon

Within the study period the flux of POC during the summer period ranged between 25 and $45 \text{ mg m}^{-2} \text{ d}^{-1}$. These values are comparable to the fluxes measured at open water stations during short-time deployments conducted in the Spitsbergen region during summer 1991 (Andreassen et al., 1996). Export of POC in the shallow Barents Sea, as measured in several years with short-term sediment trap deployments, amounted to $100\text{--}200 \text{ mg m}^{-2} \text{ d}^{-1}$ during summer and up to $750 \text{ mg m}^{-2} \text{ d}^{-1}$ during the spring bloom events, and thus was considerably larger than the export measured during our study (Olli et al., 2002; Wassmann et al., 2006). The annual organic carbon export in the Barents Sea is estimated at $\sim 40 \text{ g m}^{-2}$, which is about $2/3$ of the new production of $\sim 60 \text{ g m}^{-2}$ in this region (Wassmann et al., 2006).

Measured annual POC sedimentation at $\sim 300 \text{ m}$ depth during our study varied between 1.6 and 2.5 g m^{-2} (Table 3) and is similar to fluxes measured in the central Arctic Ocean (Fahl and Nöthig, 2007). To estimate the proportion of production that is exported we use evaluations of new production from the nearby Greenland Sea. Here this production was calculated to range between 30 and 57 g m^{-2} (Noji et al., 1996; Slagstad et al., 1999; Anderson et al., 2000). These comparisons clearly highlight the fact that only a minor part ($< 10\%$) of the organic matter produced in the euphotic layer is exported to greater depths in the HAUSGARTEN region, considerably less than in the Barents Sea. This also holds true when the probable loss of particulate carbon to the dissolved phase of the trap samples is accounted for (Noji et al., 1999b; Kähler and Bauerfeind, 2001). Contrary to the observations in the Barents Sea, most of the organic matter is retained in the water layers above the sediment traps, which implies an effective consumer community and a tight coupling in the upper pelagial. On a long-term (annual) scale this retention potential is rather constant, as we measured only little inter-annual variation in the flux of organic and

biogenic matter (Table 3). The seasonally resolved patterns, on the other hand, regularly exhibit short-term sedimentation events (Fig. 3), thus indicating a temporary decoupling in the pelagic foodweb system. However, differences in the composition of organisms within the sedimented material and in the seasonal sedimentation patterns were observed during our study, which can be partly explained by variability in the hydrography and ice coverage in the region.

5.3. Hydrographic factors and ice

The ambient hydrographical conditions are also of great importance as they influence the prevailing environmental conditions of the production regime through stratification or vertical mixing, thus governing nutrient supply and biomass formation in the euphotic zone. The presence or absence of ice also fosters pelagic production, through influencing light penetration and stabilizing of the near surface water layer by melt water formation.

The competition between northward flow of AW along the northern tip of the Knipovich Ridge and southeastward flow of recirculating AW results in strong variations of current directions over short-time scales (Fig. 1b). This flow pattern is also representative for the position of the sediment trap mooring, where an interchange between the northwestward flow of AW from the offshore part of the WSC and the southeastward flow of modified AW recirculating in the cyclonic eddy may be expected in the upper layers.

These variations of the currents certainly influence the shape of the statistical collection funnel of the sediment traps (Siegel and Deuser, 1997; von Gyldenfeldt et al., 2000; Siegel, et al., 2008) as well as the particle composition. Assuming sinking velocities of $\sim 100 \text{ m d}^{-1}$ (Bauerfeind et al., 1994) and mean current velocities of between 10.9 and 13.1 cm s^{-1} (Fig. 6) the particles collected at $\sim 300 \text{ m}$ depth should originate from the upper layers $\sim 28\text{--}34 \text{ km}$ around the mooring position. However, the catchment areas may vary considerably between consecutive sampling intervals because of short-term changes of current velocities and directions.

An impression of the prevailing current conditions and an indication of the geographical origin of collected particles can be obtained from the progressive vector diagrams (PVD-T), also displaying water temperature (Fig. 6). The diagrams clearly indicate the large discrepancies between consecutive years as well as variations on shorter time scales. This holds true for both the direction of the currents and the temperature in the upper water layer and reflects the varying influence of warm Atlantic and cold Arctic water masses.

A northward displacement of the water in the surface layer was observed during the years 2000–2002 (Fig. 6a and b), while a southward movement has prevailed since December 2002. However, during the whole period of observations, meandering of the offshore part of the WSC resulted in long-lasting east–west dislocations, accompanied by slightly increased temperatures. Beside these long-term fluctuation, short-term see–saw changes in all directions occurred, most possibly created by mesoscale eddies passing through the area.

Unusually elevated temperatures ($\geq 3.5^\circ\text{C}$) were measured over extended periods of time during the last mooring period 2004/2005 (Fig. 6e). Temperatures within this range were encountered also during the first month of the period 2002/2003 but otherwise occurred only sporadically (Figs. 6).

A decrease of the AW temperature during the mooring period 2002/2003 (Fig. 6c) can be attributed to the longer travel in the cyclonic gyre and an addition of Arctic water and melt water encountered during this excursion. The same water mass, including the particulate material had to move through the central HAUSGARTEN area, after (in case of northward flow) or before (in case of south-eastward flow) it was observed at the mooring F6.

The influence of cold water masses was most obvious in 2003, when the longest duration of ice coverage was observed for the whole year, as well as for the summer period (Fig. 2). The ice was most probably transported from regions northwest of the mooring position into the study area by the currents, which were directed persistently to the southeast after January 2003 (Fig. 6c). In the same period the seasonal pattern in total flux distinctly deviated from the pattern observed in the preceding years, and a strong rise in total matter sedimentation starting in April/May occurred (Fig. 3e). The intercepted material during this period was dominated by lithogenic matter, which also predominated with 73% of the total annual flux in 2002/2003 (Table 3). In regard to the prevailing current direction at the mooring position, this material can only stem from the ice. This is corroborated by the intermittent presence of benthic foraminifera and sand grains, particles that possess high sinking velocities, as well as the intermittent dominance of sterols indicating a greater amount of terrigenous particles in the samples (Fig. 4c). Parallel to the rise in total flux, the sedimentation of POC, bPSI and biogenic matter in general also increased (Fig. 3a–d).

The parallel increase of biogenic and lithogenic material in the samples during spring and summer 2003 can be explained by the simultaneous presence of ice-released lithogenic matter and the formation of great amounts of biologically produced organic matter in the upper water layer. These conditions favour the formation of organo-mineral complexes (Ittekkot, 1993; Hamm, 2002; Passow and De la Rocha, 2006) by which the export of particulate matter is facilitated, resulting in elevated sedimentation. Such an effect on sedimentation, comparable to the observation at the HAUSGARTEN site, was also described in the region of the East Greenland Current during periods of ice melt (Bauerfeind et al., 2005). Not only was increased sedimentation observed when the ice edge matched the position of sediment traps, but an enhancing effect on sedimentation can also exist several tenths of kilometers away from ice edge, as reported by Ramseier et al., (1999).

5.4. Species sedimentation pattern

In the trap samples we observed species assemblages that indicate the influence of the warm Atlantic water masses in the upper water layer throughout the whole

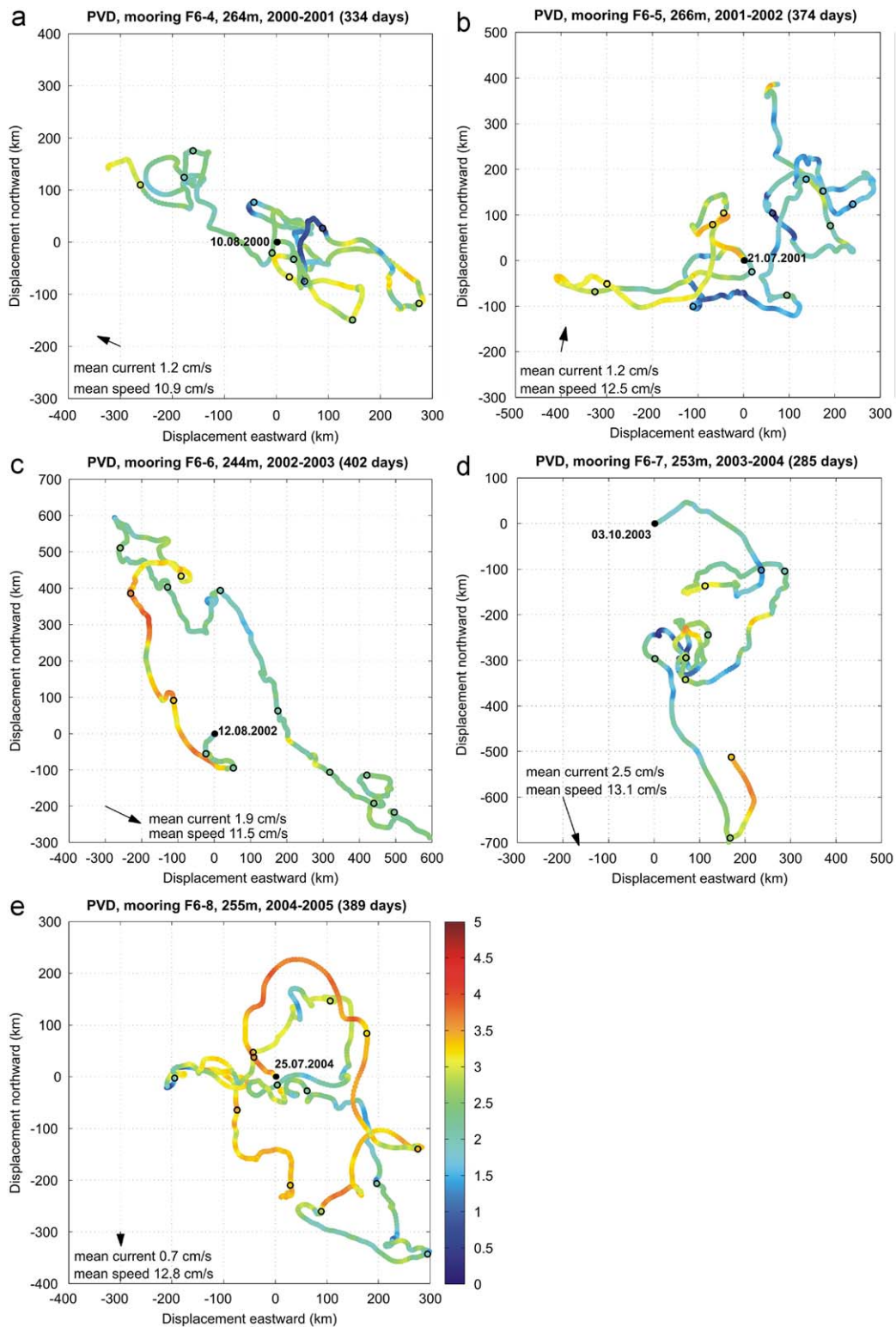


Fig. 6. (a–e) Progressive vector diagrams (PVD-T) and colour-coded temperatures at ~250 m obtained from an oceanographic mooring close to the HAUSGARTEN mooring for the years 2000–2005. The starting dates are given in the diagrams; dots represent 1 month periods. Arrows denote the direction of the mean current.

study period. Organisms of this kind are the pteropod *Limacina retroversa*, the coccolithophore *Emiliania huxleyi* and diatoms of the *Rhizosolenia/Proboscia* group.

On the other hand, species that indicate the influence of cold water masses were also regularly observed. During the time period with elevated fluxes in May/June 2003, diatoms, most notably pennate forms, dominated the flux of recognizable cells (Fig. 3e–g, Table 2). *Fragilariopsis* spp. (mainly *Fragilariopsis cylindrus*) was the most dominant organism, accompanied by species of the genus *Navicula* and *Nitzschia*. These species are regarded as cold-water and ice-associated organisms (von Quillfeldt, 2000, 2004) and underpin the influence of ice on sedimentation during the early summer 2003.

Very few pteropods were present in the samples in the same year. They consisted almost exclusively of the cold-water-adapted species *Limacina helicina* (Lalli and Gilmer, 1989), whereas the warm-water-adapted *Limacina retroversa* was regularly observed during the other mooring periods and also dominated in some of the samples (Fig. 3b). Generally the patterns of pteropod fluxes during our study were similar to the pattern observed in ~2000 m in Fram Strait (Meinecke and Wefer, 1990); however, the quantity of organisms at ~300 m was considerably (~10 fold) larger than in deep sediment traps.

Among the coccolithophorids present in the samples, the cold-water-adapted species *Coccolithus pelagicus* was clearly outnumbered by *Emiliania huxleyi*, which predominated almost exclusively (Table 2). The latter species, although described as being cosmopolitan, preferably thrives in warm waters (Tyrell and Merico, 2004) and was most possibly transported with the North Atlantic and West Spitsbergen Currents to the HAUSGARTEN area. However, the continuous occurrence of *E. huxleyi* in the sediment trap samples may also indicate a shift in the structure of plankton communities in the area in recent years, as this species was observed only occasionally in the water column in a multi-year study conducted during 1987–1995 west of Spitsbergen (Baumann et al., 2000). The authors also reported a dominance of *C. pelagicus* in samples from the surface sediments in the same area, thus indicating the importance of this cold-water-adapted species in the past. Contrary to the observation in surface sediments we noted a clear dominance of *E. huxleyi* in the sediment trap samples at 300 m during 2000–2005. A possible shift in the abundance of *E. huxleyi* is further corroborated by the continuous observation of blooms of this species in the southern Barents Sea in 1999–2003 and its occurrence in great quantities in the water column northeast of Spitsbergen at 80–81°N in summer 2003 (Smyth et al., 2004; Hegseth and Sundfjord, 2008). All these observations might be related to the ongoing shift in hydrographical conditions, in particular to changes in the Atlantic water inflow and increased heat transport to the area (Polyakov et al., 2005; Schauer et al., 2008), setting the stage for the continued existence of these warm-water-adapted species in the subarctic and arctic regions.

The contribution of coccolithophorids to the flux of carbonate and total organic carbon presumably was minor, despite the high share in the numbers of recognizable cells, because of the small size of these organisms.

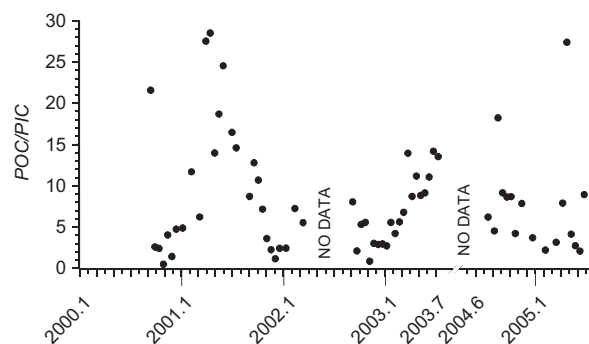


Fig. 7. Particulate organic to particulate inorganic carbon (POC/PIC) ratios (by weight) in the sedimented material.

This is indicated by the ratios of particulate organic to particulate inorganic carbon (POC/PIC), which points to a dominance of non-calcareous organic material during almost the whole period of the study (Fig. 7, Table 3). Low ratios (~1) coincided with periods of elevated pteropod presence in the samples (Fig. 3). Apart from these periods during September–December, PIC apparently is of little importance in carbon export in the area. This observation is well in line with results reported by Takahashi et al. (2000) and Waniek et al. (2005) from the North Pacific and North Atlantic and reflects the dominance of diatoms and organisms other than coccolithophorids in production and export under the current environmental conditions at high latitudes.

During the last mooring period in 2004/2005, the amount of recognizable cells decreased considerably, most notably in the numbers of diatoms (Figs. 3g and 4). This decrease was paralleled by low fluxes of bPSi, whereas the flux of POC at $\sim 50 \text{ mg m}^{-2} \text{ d}^{-1}$ was very high during July/August 2004. The annual POC flux was not distinctly different from the previous mooring periods, whereas the amount of bPSi was the lowest observed in the time period 2000–2005 (Table 3). Therefore, the exported organic carbon originated from sources other than diatoms or coccolithophorids as also indicated by the POC/PIC ratios. In the same period, we noticed large amounts of non-identifiable amorphous detritus in the samples. From the concurrent rise of marine organic matter and brassicasterol in the biomarker composition (Fig. 5) as well as the decrease in diatom numbers, we assume, that this material was composed mainly of prymnesiophytes, most probably *Phaeocystis* sp.. This organism produces brassicasterol (Smith et al., 1989; Skerratt et al., 1995), is known to form blooms in the Nordic Seas and may also contribute to particle export (Smith et al., 1991; Bauerfeind et al., 1994; Olli et al., 2002; Reigstad and Wassmann, 2007); however, it is almost unrecognizable in trap samples.

Specific species show a distinct seasonal sedimentation pattern like the bulk and biochemical components. Nevertheless, during the entire period of the study we observed organism assemblages in the sediment trap samples indicating the influence of warm Atlantic as well as cold Arctic water masses on the composition of the

plankton community. The coexistence and the fluctuating abundances of these organisms define the HAUSGARTEN long-term observatory as a model area for expected changes in plankton communities in future polar marine ecosystems. Where in the future ice coverage will decline during summer and become more variable because of the expected increase in heat transport, warm-adapted species may become an established and a generic component within the plankton community. Although our study comprises flux measurements over a period of 5 years, this period is far too short to permit a sound prediction on possible changes in the structure of the pelagic environment due to the projected warming, and it clearly emphasizes the need for long-term studies in Arctic regions.

6. Conclusions

- Our studies on sedimentation at the deep-sea long-term observatory HAUSGARTEN during the years 2000–2005 exhibited a distinct seasonal signal with elevated fluxes during May/June and at the end of the growth season.
- Export of particulate organic carbon and its inter-annual variation at HAUSGARTEN observatory was rather low and indicates an efficient retention and recycling of particulate organic matter in the water above 300 m.
- From the composition of the sedimented matter it appears that export of organic carbon mainly is governed by non-calcareous organisms at present.
- Variations in the surface currents and ice regime seemingly trigger changes in patterns and composition of sedimenting matter and plankton communities in the eastern Fram Strait.

Acknowledgements

We greatly acknowledge the help of the crew of R.V. *Polarstern* during the work at Sea. We thank E. Schütt and M. Monsees for the assistance in mooring deployment and recovery, S. Haase, who counted the first set of samples and B. Wend for the tedious work of swimmer picking. We thank M. Crawford and M. Bergmann for correcting the English of the manuscript. Suggestions of 3 anonymous reviewers and comments of M. Bacon and T. Trull are also acknowledged. We dedicate this article to our friend and colleague J. Wegner, who passed away unexpectedly and who was engaged in the work at the HAUSGARTEN since the beginning in 2000. This work was financed by institutional funds of the Alfred Wegener Institute for Polar and Marine Research Bremerhaven, Germany and also by the EU-project HERMES (EC Contract No. GOCE-CT-005-511234). This is Publication no. awi-n17715.

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