The first annual record of lithogenic and biogenic particle fluxes in the central Arctic Ocean: Vertical versus lateral input on the Lomonosov Ridge

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Background and Introduction

Investigations of lithogenic and biogenic particle fluxes using long-term sediment traps are still very rare in the northern high latitudes and restricted to the arctic marginal seas (e.g., Beaufort Sea, Kara Sea) and sub-arctic regions (e.g., Fram Strait, Greenland Sea and Bering Sea). Here, for the first time, data on the variability of fluxes of lithogenic matter, carbonate, opal, and organic carbon as well as biomarker composition from the central Arctic Ocean are presented for a one-year period. The study has been carried out on material obtained from a long-term mooring system equipped with two multi-sampling-traps (20 sampling cups; 150 and 1550 m water depth, respectively) and deployed on the southern Lomonosov Ridge close to the Laptev Sea continental margin (81°04.1'N, 138°56.1'E) from September 1995 to August 1996. In addition, data from surface-sediments were included in the study to get more information about the flux and sedimentation of organic carbon in this area.

Both the shallow as well as the deep trap show significant differences in vertical flux values over the year. Higher values were found from mid-July to end of October (total flux of 75-130 mg m^{-2} d^{-1} in the shallow trap and 40-225 mg m^{-2} d^{-1} in the deep trap). During all other months, fluxes were fairly low in both traps (most total flux values <10 mg m^{-2} d^{-1}). The interval of increased fluxes can be separated into (1) a mid-July/August maximum caused by increased primary production as documented in high abundances of marine biomarkers and a change in diatom abundances, and (2) a September/October (absolute) maximum caused by increased influence of Lena river discharge indicated by high portions of terrigenous/fluvial biomarkers in both traps. Here, total fluxes in the deep trap were significantly higher than in the shallow trap, suggesting a lateral sediment flux at greater depth.

Annual fluxes of lithogenic matter, carbonate, opal, and particulate organic carbon are 3.9 g m^{-2} y^{-1}, 0.8 g m^{-2} y^{-1}, 2.6 g m^{-2} y^{-1}, 1.5 g m^{-2} y^{-1}, respectively, at the shallow trap and 11.3 g m^{-2} y^{-1}, 0.5 g m^{-2} y^{-1}, 2.9 g m^{-2} y^{-1}, 1.05 g m^{-2} y^{-1}, respectively, at the deep trap.

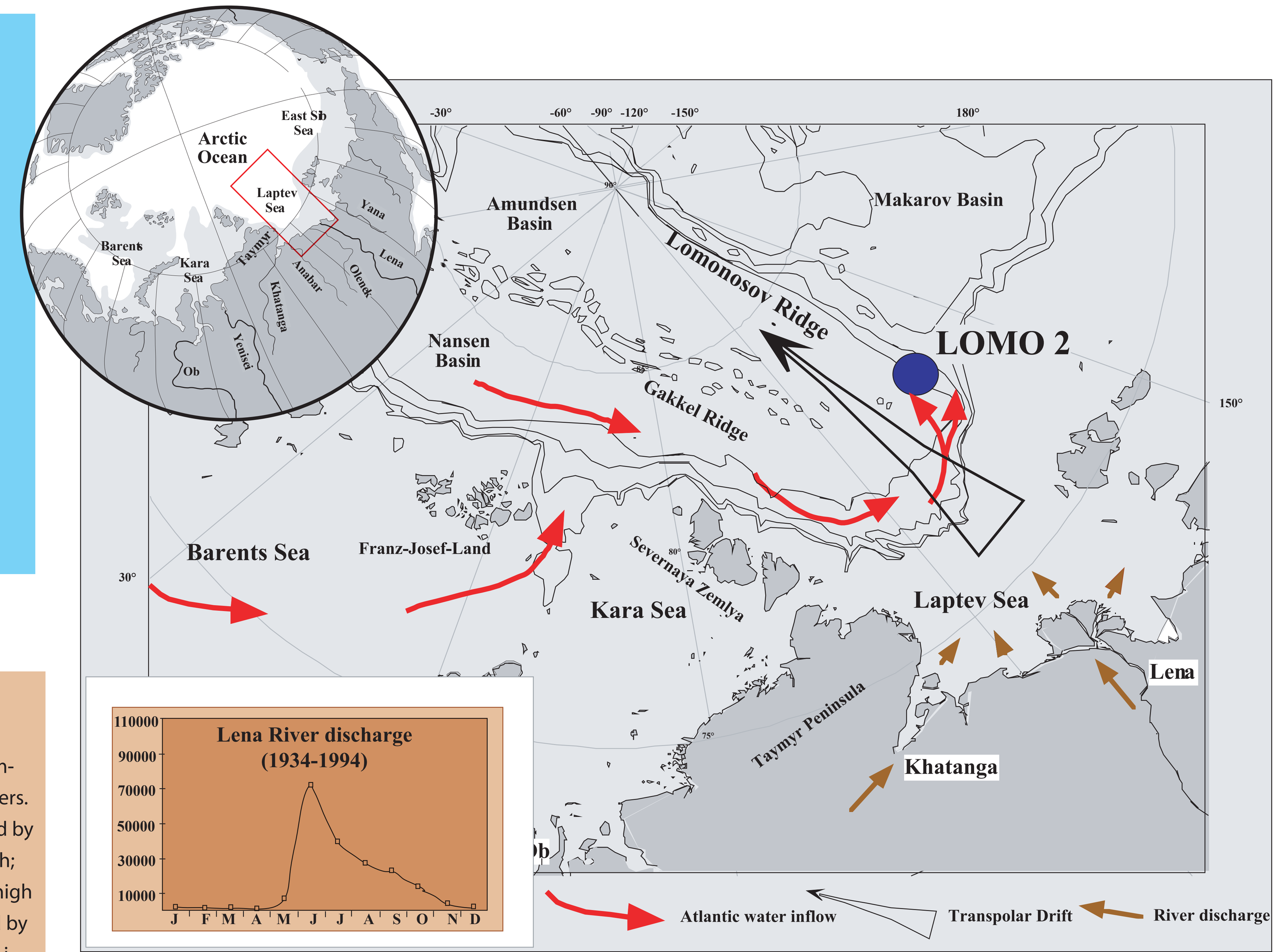

Fig. 1

Results and Discussion

Our data from the long-term sediment traps presenting the time interval from September 1995 to August 1996, reflect a seasonality in all measured and calculated parameters. We can distinguish three different periods during the year: First, a period characterized by low productivity, low fluxes and strong sea-ice cover (second half of November - March; Winter phase); second, a period characterized by ice-melting, ice-free conditions and high biogenic matter flux (April to August; Biogenic phase), and third, a period charcterized by ice-free conditions and highest lithogenic matter flux (September to end of October, Lithogenic phase). These characteristics are obvious in the shallow (150 m) and the deep (1550 m) trap, although flux values and particle composition are somewhat different in the two traps. The lithogenic phase will be discussed on this poster in more detail.

From September to the end of October the terrigenous character (see Figs. 2a and 3a) of the material transported downwards to the sea floor during these ice-free months is clearly pronounced. The biological production is only of minor importance during this time as also supported by the microscopical data which show mostly empty diatom valves in both water depths. This causes the relativly high opal fluxes (Fig. 2b) especially in 150 m water depth, where the cells without chloroplasts were dominated by *Melosira arctica* and with chloroplasts by *Fragilariopsis oceanica* (Zernova et al., 2000).

A remaining question, however, is where the trapped terrigenous material comes from. Focussing on 150 m water depth we assume that the terrigenous particulate organic material derived from the Laptev Sea shelf (with the Lena River as a dominant source), transported with sea ice by the Transpolar Drift to the Lomonosov Ridge. In general, the sea ice is a relevant transport tool for the terrigenous organic carbon (e.g., Eicken, 2004).

Foccussing on the ice-drift velocity we try to estimate the possibility whether the terrigenous material which is trapped in 150 m due to ice melting in September/October, can be related to the main Lena River outbreak in June (Fig.1). Different values for the ice velocity were published but 0.1m/s seems to be a moderate estimate (Haas, pers. com). Using this velocity and a distance to the Lomonosov Ridge of about 850 km, the sea-ice-associated sediments would reach the investigation area in nearly three months. This is only a rough estimate but it seems to support that there is a correlation between the high terrigenous flux in the traps in September/October and the Lena River outbreak in June. We have to consider, however, that no fluvial-derived diatoms could be determined in the traps. This fact is supported by investigation from the Kara Sea where fluvial-derived diatom cells in the southern part off the Yenisey were empty or destroyed when entering the saline water (Gaye et al., 2006).

In 1550 m water depth the source of the trapped material seems to be different. The order-of-magnitude higher total flux values (Figs. 2a, 3a) correlating with high lithogenic flux values and land-derived sterol fluxes, point to a strong influence of lateral transport at the deep trap. The most probable transport is related to the Atlantic and intermediate water layers which carry material from the Barents and Kara Seas along the Eurasian continental margin and recirculate northwards to the Amundsen Basin, passing the trap position (Rudels et al., 2000).

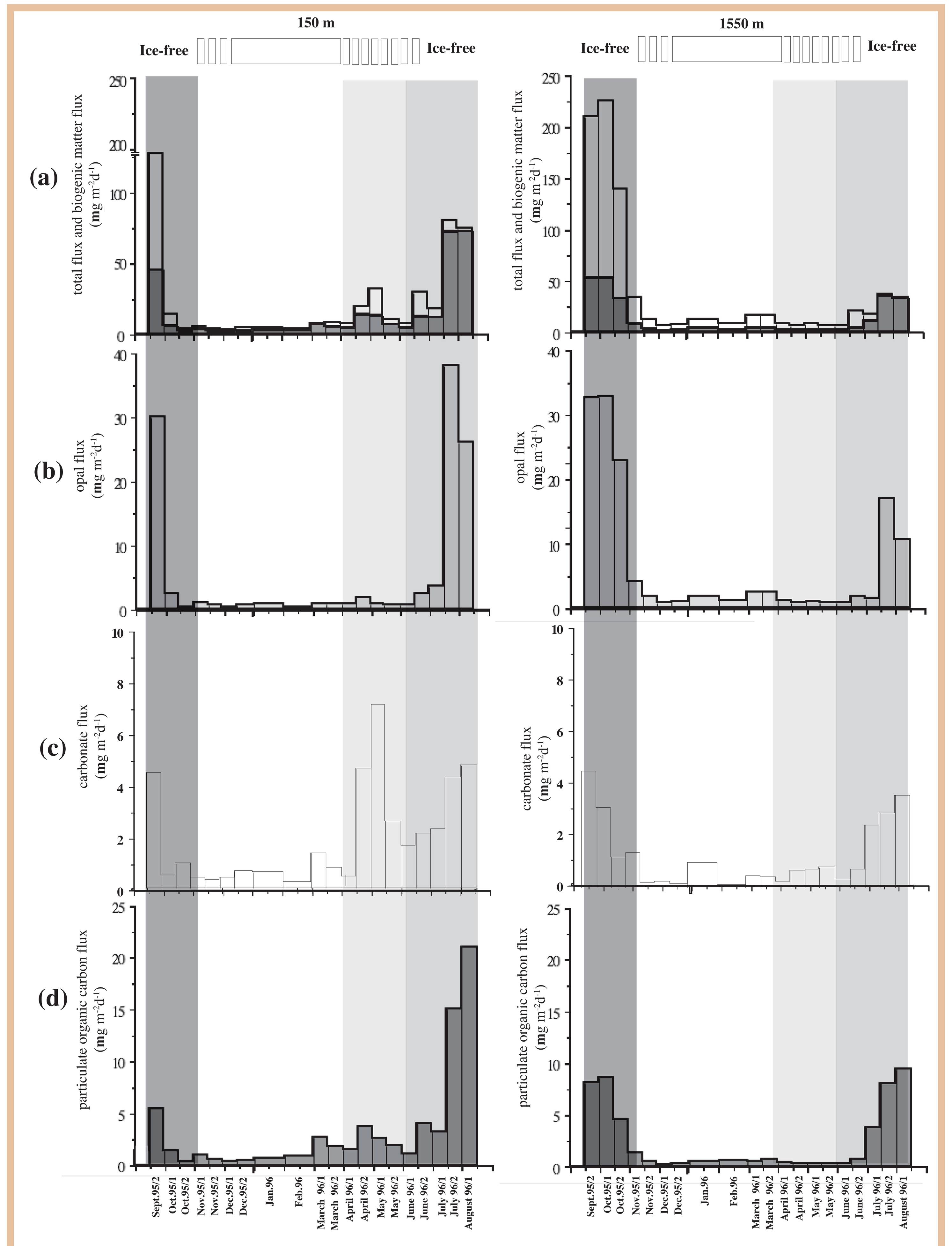

Fig. 2

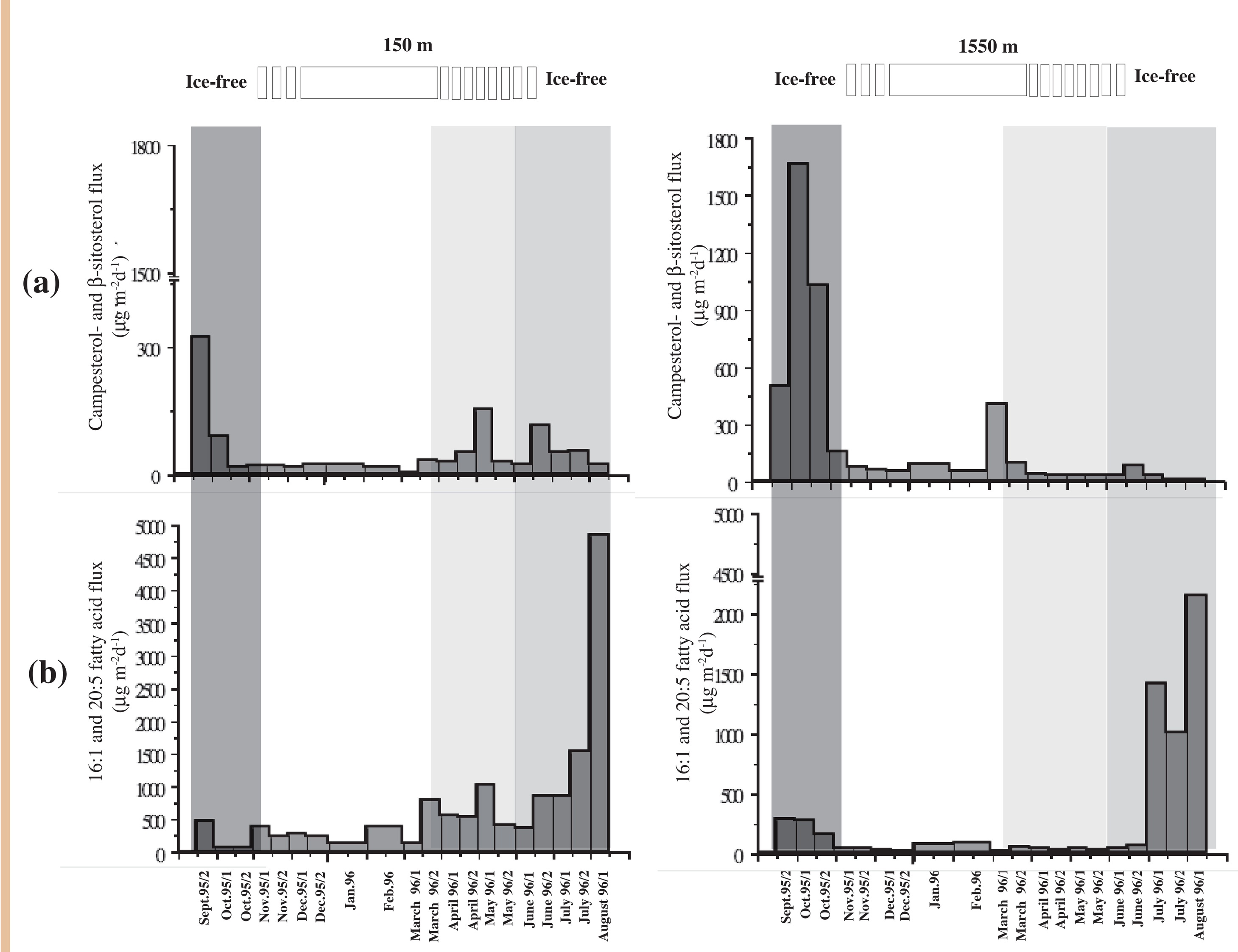

Fig. 3

To estimate the relevance of the lateral transport we calculate the portion of the lateral transported lithogenic fraction and terrigenous carbon. First we calculate the lateral proportion of flux based on the lithogenic flux data. This results in a lateral transport of lithogenic material of 64%. Second, using the primary production according to Boetius and Damm (1998) and the depth-dependent degradation of marine organic carbon after Betzer et al. (1984), we calculate the terrigenous organic carbon proportion in 150 m assuming that the lateral input in 150 m is of minor importance. In 1550 m water depth we calculated the terrigenous carbon flux under the assumption that there is no degradation of the terrigenous organic carbon. (According to Ittekott (1988), 35% of the terrigenous organic carbon belongs to the labile (metabolizable) fraction and only 65% should be available for burial. However, the long distance of the transported material from the source (here the Laptev Sea shelf) suggest that only the more stabile terrigenous fraction reaches the Lomonosov Ridge). This calculation gives a lateral transport of terrigenous organic carbon of 0.34 g $m^{-2}y^{-1}$ in 1550 m which is 42% of the terrigenous POC flux (0.81 g $m^{-2}y^{-1}$). The order-of magnitude correspondence with the lateral transported lithogenic matter supports our estimates. Considering all the assumptions used above, this seems to be a reasonable correspondence, and the number should give a reliable first-order estimate of lateral flux. Addionally, we show that Betzer et al. (1984)´s formula for calculation of carbon flux seems to work also for Arctic Ocean environments.

To show the complexity of the whole system we compared the trap data with results from near-surface sediments of Core PS2757-7 taken close to the location of the sediment trap (Stein et al., 2001; Stein et al., 2004). Based on the accumulation rates of total organic carbon (which includes the marine as well as the terrigenous proportion) (Stein et al., 2001) and the microscopical investigations of the organic carbon composition (maceral data show that 25% of the carbon is marine; Boucsein and Stein, 2000) only 0.4% of the primary produced carbon (18 g $m^{-2}y^{-1}$, Boetius and Damm, 1998) is buried. Focussing on the terrigenous portion of organic carbon in the sediments (75% based on maceral data) we found increasing values from the upper water column (trap data) to the sediment. Based on the assumption that the labile terrigenous organic compounds already have been degraded near the source of the material, we speculate that there has to be a lateral transport of organic carbon away from the sediment surface which prevents the organic carbon to be buried. On the other hand the comparison between the accumulation rate of total sediment (48 g $m^{-2}y^{-1}$; Stein et al., 2004) with the sum of lithogenic and opal fluxes in 1550 m (14.2 g $m^{-2}y^{-1}$) shows that there must be up to 30 g $m^{-2}y^{-1}$ lateral input to the surface sediment. That means, there must be different transport mechanisms causing the accumulation of particulate organic carbon and lithogenic fraction between 1550 m and the sediments surface (1700 m).

Conclusions

*** We can distinguish three different periods during 1995/1996: First the low productivity, low fluxes and ice-covered winter months (second half of November - March; Winter phase), second the higher flux period with ice-melting and ice-free conditions and high biogenic matter flux (April to August; Biogenic phase), and third the highest flux period with ice-free conditions and highest lithogenic matter flux (September to end of October, Lithogenic phase).**

*** Based on the bio-/geochemical data determined on the sediment trap material, vertical export of lithogenic matter, carbonate, opal, POC, diatom-specific fatty acids, and terrignous sterols ranges between 3.9-11.3 g m^{-2} y^{-1}, 0.5-0.8 g m^{-2} y^{-1}, 2.6-2.9 g m^{-2} y^{-1}, 1-1.5 g m^{-2} y^{-1}, 130-300 mg m^{-2} y^{-1}, 23-78 mg m^{-2} y^{-1}, respectively.**

*** Most of the autochthonous carbon is recycled in the upper 150 m (except for the diatom event July/August).**

*** In 1550 m water depths we estimate a lateral input of 42% (based on terrigenous organic carbon) and 64% (based on lithogenic matter). In addition the sea-ice associated transport is of major relevance.**

*** The investigation area is under the influence of the strong outflow of the Lena River, exhibiting relatively high vertical terrestrial POC export in September/October.**

For more details see Fahl and Nöthig (submitted to Deep-Sea Research, 2006)

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