Ocean Sci. Discuss., 7, 1017–1057, 2010
www.ocean-sci-discuss.net/7/1017/2010/
doi:10.5194/osd-7-1017-2010

Ocean Science Discussions

Suspended particles in the Canada Basin from optical and bottle data, 2003–2008

J. M. Jackson[1], S. E. Allen[1], E. C. Carmack[2], and F. A. McLaughlin[2]

[1]Department of Earth and Ocean Sciences, University of British Columbia, 6339 Stores Rd, Vancouver, BC V6T 1Z4, Canada
[2]Fisheries and Oceans Canada, Institute of Ocean Sciences, P. O. Box 6000, Sidney, British Columbia, V8L 4B2, Canada

Received: 5 May 2010 – Accepted: 13 May 2010 – Published: 26 May 2010

Correspondence to: Jennifer Jackson (jjackson@eos.ubc.ca)

Published by Copernicus Publications on behalf of the European Geosciences Union.

Suspended particles in the Canada Basin from optical and bottle data

J. M. Jackson et al.

Abstract

It is expected that coastal erosion, upwelling and increased river runoff from Arctic warming will increase the concentration of suspended particles in the Arctic Ocean. Here we analyze in situ transmissometer and fluorometer data from the summers of 2003 through 2008 and bottle-derived particulate organic carbon (POC) and total suspended solids (TSS) measurements sampled in the summers of 2006 and 2007 from the Canada Basin and surrounding shelves. By coupling these data sets, we explored the correlation of POC with beam attenuation coefficients to assess the viability of estimating POC concentrations from archived transmissometer data. We divided our study area into five regions to account for the significant spatial variability and found that POC (but not TSS) and attenuation were well-correlated over the Northwind Ridge, in the Canada Basin interior, and along the eastern shelf of the Canada Basin. We then estimated POC from attenuation for these regions and found that the average POC ranged from 16 to 37 $\mu g\,C\,kg^{-1}$ within the upper 50 m and from 14 to 23 $\mu g\,C\,kg^{-1}$ from 50–100 m. The strength of the chlorophyll maximum appeared to dominate the average POC values. In general, the eastern shelf was the least productive region in our study area. Neither TSS nor POC were well-correlated along the entire Beaufort shelf. Our interannual comparison from the summers of 2003 through 2008 found no evidence of increased particle concentrations over the Northwind Ridge, in the Canada Basin interior, or along the eastern shelf, however, this work provides a baseline of suspended POC concentrations.

1 Introduction

Climate change is predicted to increase upwelling, coastal erosion and river runoff and these effects will likely increase suspended particle concentrations in the Arctic Ocean and its surrounding shelves (Carmack et al., 2006). Particles supplied by these processes in the western Arctic Ocean (see map in Fig. 1) are primarily inorganic

OSD
7, 1017–1057, 2010

(Macdonald et al., 1998; O'Brien et al., 2005). Suspended particles influence the near-surface optical environment by scattering and absorbing sunlight, which may affect rates of primary productivity.

Historical measurements of total suspended solids (TSS i.e. both inorganic and organic particles) and particulate organic carbon (POC) in the western Arctic Ocean are limited. The first reported TSS and POC data from the Canada Basin, collected in the spring of 1968 and 1969 at Ice Station T-3, ranged from 9–56 $\mu g\,kg^{-1}$ and 2–14 $\mu g\,C\,kg^{-1}$, respectively, with the highest values of both being observed at 50 m (Kinney et al., 1971). Similar values for POC were found in April 1983 along the Alpha Ridge during the CESAR program (Gordon and Cranford, 1985). The above concentrations were among the lowest ever observed for an open ocean system, and thus the Canada Basin was described as a biological desert (Kinney et al., 1971; Gordon and Cranford, 1985). In 1994, POC samples were collected during the joint Canada-US expedition from the Chukchi Sea to the North Pole and values in the upper 100 m were about five times greater in the northwestern Canada Basin, suggesting that the Canada Basin is seasonally productive (Wheeler et al., 1997) and actively cycles carbon (Wheeler et al., 1996).

Several studies have examined the transport of particles from Arctic shelves to the Canada Basin. During ice-island T3 from 1965–1969, several nepheloid layers were identified along the Northwind Ridge that likely transported particles into the Canada Basin (Hunkins et al., 1969). At the surface, it has been found that particles in modified Mackenzie River runoff (O'Brien et al., 2005; Lalande et al., 2009) and in Lena River runoff (Burenkov, 1993; Lalande et al., 2009) can end up in the Canada Basin (Yamamoto-Kawai et al., 2009; Guay et al., 2009). Dirty sea ice can also release particles in situ if it melts (Darby, 2003). During the 2002 Western Arctic Shelf-Basin Interactions (SBI) summer cruise, several plumes of particles at various depths below 50 m were identified that likely transported matter from the Chukchi and western Beaufort shelf into the Canada Basin (Ashjian et al., 2005; Bates et al., 2005; Codispoti et al., 2005). Mechanisms to transport this material include advection through

Barrow Canyon (Ashjian et al., 2005) and eddies formed from the particle-rich along-shelf boundary current (Ashjian et al., 2005; Mathis et al., 2007).

Particle concentrations can also be approximated from transmissometer (measures light attenuation) and fluorometer (approximates chlorophyll-*a*) data, both of which have been measured more extensively in the Canada Basin and surrounding shelves than POC and TSS. It has been found that POC and TSS are well correlated with attenuation in Puget Sound (Baker and Lavelle, 1984), along the continental rise of the northwest Atlantic (Gardner et al., 1985), in the Gulf Stream (Bishop, 1986), in the Laptev Sea near the Lena River delta (Burenkov, 1993), in the equatorial Pacific (Bishop, 1999) and in the subarctic Pacific (Bishop et al., 1999). However, these relationships have not been tested in the Canada Basin.

During the summers of 2003 through 2008, CTD, transmissometer and fluorometer data were collected at stations in the Canada Basin and its surrounding shelves. In addition, POC and TSS samples were taken during the 2006 and 2007 cruises (Fig. 1). Here, we examine these data to i) identify regions of high attenuation, fluorescence, POC and TSS, to ii) determine the correlation between POC and attenuation and TSS and attenuation, and to iii) examine the interannual variability of these data.

2 Data and methods

2.1 CTD, transmissometer and fluorescence data

For this study, researchers from Fisheries and Oceans Canada in collaboration with researchers from the Japan Agency for Marine-Earth Science and Technology and Woods Hole Oceanographic Institution collected temperature, salinity, fluorescence and transmissometer data from 2003–2008 (details in McLaughlin et al., 2008). During all years, a SeaBird SBE-911 Plus CTD, a Wetlabs C-star transmissometer, and a Seapoint fluorometer were used. The cruise dates were: 13 August–3 September 2003, 5–30 August 2004, 3–31 August 2005, 7 August–12 September 2006,

OSD
7, 1017–1057, 2010

27 July–28 August 2007, and 23 July–20 August 2008. Transmissometer data were collected at 662 nm.

An initial assessment of the transmissometer data revealed significant drift (up to 2%) between years and even during the same cruise, likely due to variable frequency of cleaning the optical window. In order to compare all transmissometer data, we calibrated all profiles to station CB11, sampled on 1 September 2006 at 79° N, 150° W with a freshly calibrated Wetlabs C-star transmissometer. To perform the calibration, we assumed that the water at 2000 m at all stations in the Canada Basin (i.e. with a bottom depth greater than 3500 m) was clear. A depth of 2000 m was chosen because it was found to be the clearest water in the Arctic Ocean when the bottom depth was greater than 3000 m (Hunkins et al., 1969). At each basin station, we subtracted 90.7% (the transmissometer value at CB11 at 2000 m in 2006) from the transmissometer value at 2000 m at that station and then added this difference to each data point to calibrate the remaining transmissometer profile. For shallower stations, we averaged the calibration from the nearest basin stations. A similar calibration was done for fluorescence data. Here, the data were calibrated to the fluorometer value observed at 2000 m at CB11 in 2006 (0.0347 $\mu g\,L^{-1}$) and the basin profiles were calibrated based on the difference between the value at CB11 and the value at each station at 2000 m.

It has been shown that transmissometer output are affected by differences between the internal temperature of the transmissometer and the temperature of the seawater, especially in cold, clear water (Bishop, 1986). In particular, Bishop (1986) found that a temperature difference of about 11 °C amounts to 9–12 $\mu g\,kg^{-1}$ of total suspended solids in open oceans. Our Wetlabs C-star transmissometer, subjected to temperature stability tests, had a maximum transmissometer error of 0.02% per degree Celsius difference, which is less than half of the 0.05% transmission error per degree Celsius found by Bishop (1986). To further minimize these effects, the transmissometer was soaked at 5 m for 3 min before each cast.

OSD
7, 1017–1057, 2010

To determine the amount of light that is attenuated due to both scattering and absorption of particles, we calculated the beam attenuation coefficient (C) as $C = -\ln(\text{Tr})/r$ where Tr was the observed transmissometer value and r, the path length of the transmissometer, was 0.25 m (Bishop, 1986).

2.2 POC and TSS data

In 2006 and 2007, POC samples were taken at 5 m and 20 m, at the fluorometer maximum, at salinities 32.3, 32.6, 32.9, 33.1, 34.4, at the bottom and at any interesting transmissometer features. Nineteen stations were sampled in 2006 and 12 in 2007. Water was subsampled directly from 10 L Niskin bottles into two pre-calibrated, acid cleaned 2 L Nalgene bottles. Onboard ship, the 4 L samples were filtered onto 47 mm GF75 filters in 2006 and 25 mm GF75 filters in 2007 that had been pre-combusted at 500 °C for 4 h. A vacuum pump whose pressure did not exceed 7 psi was used during filtration. The filtration castles were rinsed down with DMQ water just before the filtration was complete. The filters were then placed in a labeled 50 mm glass Petrie dish and frozen at –20 °C. The filtration time and the volume of water filtered were recorded and filtration was performed within 4 h of sampling.

Once on shore, the filters were dried for 24 h at 50 °C, HCl fumed for 48 h, then dried again at 50 °C for 24 h, wrapped in aluminum foil and pressed into pellets. The pellets were analyzed using a Carlo Erba CN analyzer, located in the Department of Earth and Ocean Sciences at UBC, to determine POC. Sulfanilamide and blank cups were used as standards. Duplicates were taken at least once per cast in 2007 and the average standard deviation of these 12 duplicates was 5.7 µg C kg^{-1}.

TSS samples were taken at 5 m, 20 m, at the fluorometer maximum and at any interesting transmissometer feature in 2006. In 2007, samples were taken at the sample depths as the POC samples. In 2006, 16 stations were same and in 2007, 12 stations were sampled. Water was subsampled directly from 10 L Niskin bottles into two or three pre-calibrated acid cleaned 2 L Nalgene bottles. Onboard ship, 4–6 L were filtered onto 47 mm 0.4 µm polycarbonate nucleopore filters that had been acid cleaned,

Discussion Paper | Discussion Paper | Discussion Paper | Discussion Paper |
OSD
7, 1017–1057, 2010
Suspended particles in the Canada Basin from optical and bottle data
J. M. Jackson et al.

rinsed with DMQ water, dried at 50 °C and pre-weighed to 0.001 mg. A vacuum pump that did not exceed 7 psi was used during filtration. The filtration castles were rinsed down with DMQ water just before the filtration was complete. The filters were rinsed with 3% ammonium carbonate solution after filtration was complete, placed in a labeled 50 mm plastic Petrie dish, and frozen at −20 °C. The time of filtration and the volume of water filtered were recorded and filtration was performed within 4 h of sampling.

Once on shore, the TSS samples were dried at 50 °C for 24 h and then weighed. The TSS concentration was equal to the final weight minus the initial weight divided by the volume of water filtered. In 2006, the Satorius LE225D scale used to pre-weigh the filters was not available and a Mettler Toledo XP205 scale was used instead. By comparison of pre-weighed Petrie dishes, it was found that the Petrie dishes weighed on average (with standard deviation) 0.00057(±0.00009) g less on the new scale so 0.00057 g was added to the final weight of the filters. The Mettler Toledo XP205 scale was used in 2007. Duplicates were taken at least once per cast in 2007 and the average standard deviation of these 12 duplicates was 19.4 µg kg^{-1}.

3 Results

As an initial evaluation of the sensor and bottle data showed substantial spatial variability, we chose to divide the data into five different geographic regions for analysis (Fig. 1). These are i) the eastern Beaufort shelf, a shelf-slope area in the southeast with a bottom depth less than 3500 m that is influenced by outflow from the Mackenzie River; ii) the western Beaufort shelf, a shelf-slope area with a bottom depth less than 3500 m that includes Barrow Canyon; iii) the eastern Northwind Ridge slope, a feature with depths from about 950–3500 m between the Northwind Abyssal Plain and the Canada Basin, iv) the Canada Basin interior, with a bottom depth greater than 3500 m; and v) the eastern Canada Basin shelf, a shelf-slope area with a bottom depth less than 3500 m that lies between Banks and Prince Patrick Islands. Average profiles of

OSD
7, 1017–1057, 2010

beam attenuation, fluorescence, POC and TSS within each region were prepared for comparison.

3.1 The eastern Beaufort Shelf

Overall, the highest TSS concentrations (maximum 1789 $\mu g\,kg^{-1}$ in the surface water in 2006) were observed in the eastern Beaufort shelf. The average profiles of beam attenuation (Fig. 2) showed that the water was relatively clear below about 250 m, with the most particle-rich water in the upper 25 m. In this region, the highest attenuation, POC and TSS were seen above 10 m in 2006. In 2007, the surface water also had high attenuation but relatively low TSS and POC concentrations. It is likely that the source of particles in this area was the Mackenzie River, however, it is interesting that, based on oxygen isotopes and alkalinity, Yamamoto-Kawai et al. (2009) found about double the amount of Mackenzie water here in 2007 than 2006. O'Brien et al. (2005) attribute much of the spatial and temporal variability in this region to the strength of the Mackenzie plume during freshet and to variable wind transport, which may either cause resuspension of particles during north-westerly winds or erosion of coastlines during south-easterly winds. Proshutinsky et al. (2009) found that the predominant wind direction along the eastern Beaufort shelf was south-easterly during both 2006 and 2007, however, the winds were more upwelling favourable in 2007 so more coastal erosion would be expected in 2007. Thus, it is likely that the higher surface particle concentrations observed in 2006 were due to a higher Mackenzie River particle load. Below the surface, attenuation was low in 2006 although a fluorescence and POC signal at about 50 m indicate the ubiquitous deep chlorophyll maximum (Lee and Whitledge, 2005; Nishino et al., 2008; Tremblay and Gagnon, 2010). In 2007, a feature at 20 m that was associated with high fluorescence and POC values suggest that the chlorophyll maximum was shallower in 2007 than 2006. In general, the water column had higher attenuation and TSS concentrations in 2006 than 2007.

OSD

7, 1017–1057, 2010

Suspended particles in the Canada Basin from optical and bottle data

J. M. Jackson et al.

3.2 The western Beaufort Shelf

We found that the western Beaufort shelf had the highest observed POC concentrations of the study area (Fig. 3), with a maximum value of 192 µg C kg^{-1} at 5 m over the shelf in 2006, similar to surface water values sampled at the same location during the 2002 SBI (Bates et al., 2005). In 2007, the surface water also had high attenuation, however, POC was low, indicating that most of the particles were inorganic. Below the surface, the western Beaufort shelf also had the most variable attenuation profile, with three main attenuation features above 1000 m in 2006 and five in 2007.

In 2006, the three features were i) A high POC, high fluorescence signal at about 25 m that represents the chlorophyll maximum; ii) High attenuation from about 75–100 m that had low POC; and iii) A high POC layer from about 100–200 m that was observed in an eddy of cold Pacific winter water (PWW, defined by a salinity of 33.1 as per Coachman and Barnes, 1961). During the 2002 SBI project, Ashjian et al. (2005) found high concentrations of marine snow (up to about 20 µg C kg^{-1}) within PWW at the same location. We found similar POC concentrations of up to 29 µg C kg^{-1} within PWW. In 2007, the five attenuation features were i) The high fluorescence, high POC chlorophyll maximum from 30–50 m; ii) Near 100 m, there was non-fluorescent water with a very high TSS concentration of 806 µg kg^{-1}. This feature was within Pacific Summer Water (salinity of 32.7) and, as described by Pickart (2004), the sloping isohalines (not shown) indicate the eastward flowing Beaufort shelfbreak jet. High concentrations can thus be explained by shear-induced re-suspension of particles caused by the current; iii) A high POC (up to 46 µg C kg^{-1}) and TSS (up to 180 µg kg^{-1}) signal within PWW that was likely marine snow; iv) An attenuation feature at about 400 m within Atlantic water (salinity of 34.83). This feature was most apparent in the shallow station (bottom depth of 500 m), thus it could be from particle resuspension associated with a boundary current of Atlantic water; v) An attenuation feature at about 1000 m. This water had a salinity of 34.88 and the station had a bottom depth of 2000 m.

OSD
7, 1017–1057, 2010

3.3 The eastern Northwind Ridge slope

The attenuation features in the Northwind Ridge were all above 100 m (Fig. 4). In 2006, a non-fluorescent, low-POC feature was observed at about 20 m that was not apparent in 2007. From the same 2006 cruise, Jackson et al. (2010) found a summer halocline at this depth and Yamamoto-Kawai et al. (2009) observed a relatively high fraction of sea ice melt at the surface. Thus we suggest that the particles at 20 m were primarily inorganic and were released from melting sea ice, then trapped within the strong summer halocline that was formed when the ice melted. The attenuation maximum in this region had high-fluorescence, high POC, and was at a depth of about 50 m. This deep chlorophyll maximum had much higher fluorescence values in 2006 than 2007, however the average POC (with 95% confidence interval) was 64±22 µg C kg^{-1} in 2006 and 47±8 µg C kg^{-1} in 2007. Thus, POC concentrations at the chlorophyll maximum were not statistically different between the two years.

3.4 The interior of the Canada Basin

Similar to the Northwind Ridge, the main attenuation features in the Basin region were observed in the near-surface waters (Fig. 5). There were also some differences between 2006 and 2007. Within the upper 20 m, two features were observed in 2006 and one feature in 2007. In 2006, the two features were at the surface and at about 20 m. Both were non-fluorescent and the surface particles had relatively high POC concentrations while the 20 m particles were primarily inorganic. There was considerable sea ice melt during our sampling in 2006, and more open water in 2007, thus the surface particles observed in 2006 could have been recently deposited from the melting ice. In 2007, a non-fluorescent feature that had relatively high POC was observed at about 10 m. The summer halocline shoaled from 2006 to 2007 (Jackson et al., 2010), thus we suggest that this caused the near-surface attenuation feature to shoal from about 20 m in 2006 to 10 m in 2007.

OSD
7, 1017–1057, 2010

The highest attenuation was the deep chlorophyll maximum at about 50 m. Similar to the Northwind Ridge, fluorescence was greater in 2006 than 2007, indicating higher primary production in 2006. The average POC concentrations (with 95% confidence intervals) were 31±11 µg C kg^{-1} in 2006 and 27±4 µg C kg^{-1} in 2007, which is lower than the values found near the Northwind Ridge but about double those found in the central Basin in April and May by (Kinney et al., 1971) and Gordon and Cranford (1985).

An anomalous attenuation feature was observed at a depth of about 150 m within PWW (salinity=33.1) in 2006 that was correlated with slightly higher POC values. Although not apparent in the attenuation profile, the highest average TSS concentrations were also observed within PWW in 2007. These results suggest that some particles are transported into the basin within PWW.

3.5 The eastern shelf of the Canada Basin

The eastern shelf region was sampled only in 2007 because this region is usually inaccessible due to ice thickness. A general observation of this region was that the attenuation, fluorescence, POC and TSS concentrations in the upper 100 m were lower than any other non-basin region (Fig. 6). Overall, four attenuation features were observed. These were i) The attenuation maximum, which was located at the surface and had low fluorescence and relatively high POC concentrations; ii) The fluorescence maximum that was at a depth of about 60 m. Here, both the fluorescence and POC were much lower than other shelf-slope regions, suggesting that this is one of the least productive areas; iii) An attenuation feature at about 200 m that was just above the TSS maximum. The TSS peak was centred at 129.2° W and was observed from about 320–370 m, within the salinity range 34.74–34.78. This feature had the highest observed TSS concentration of the region (263 µg kg^{-1}), and given the slightly tilted isopycnals (not shown), could be from re-suspension due to the passage a boundary current transporting Atlantic water. It is interesting to note that there was a TSS peak at the salinity 32.9 and a POC peak at the salinity 33.1 that were not observed in the attenuation profiles. iv) The fourth feature was within the salinity range 34.82–34.86

from 446 m to the bottom (492 m) and suggest the presence of a bottom nepheloid layer at the 500 m depth station.

3.6 Attenuation from the shelf to the basin

Our results showed that there were several profiles along the continental slope that had high attenuation either along the bottom as nepheloid layers or in the water column within different water masses. To compare these features among regions, we contoured attenuation from shelf to basin for the eastern Beaufort shelf region, the western Beaufort shelf region, the eastern Northwind Ridge slope region and the eastern shelf of the Canada Basin in 2007 (Fig. 7). In the eastern Beaufort shelf region, most of the particles were observed at the surface and there was a small nepheloid layer along the slope. Overall, the western Beaufort shelf region had the highest attenuation below 100 m. Here, we found that particles at about 400 m (salinity 34.83) and 1500 m (salinity 34.92) extended to at least 72° N in the basin. The lowest attenuation below 100 m was seen at the Northwind Ridge and no nepheloid layer was found. Along the eastern shelf, we found the highest attenuation along the slope after the western Beaufort shelf, suggesting the presence of a significant nepheloid layer to about 800 m.

Results from the attenuation, fluorescence, POC and TSS data collected during the summers of 2006 and 2007 indicate six relatively consistent attenuation features and several irregular attenuation features in the Canada Basin. The six main features are found within i) surface water, ii) the summer halocline, iii) water that has high fluorescence, iv) cold Pacific Winter Water within the salinity range 32.9–33.1, v) Atlantic water within the salinity range 34.4–34.85, and vii) samples taken at the bottom. Of these features, only the first three are found in the basin region and are generally at depths less than 70 m. These near-surface features can have both high POC and TSS concentrations. All six features were found at various locations on the shelves and slopes surrounding the Canada Basin. Thus, particle concentrations within the Canada Basin have significant spatial variability.

4 Correlation between attenuation and POC and TSS

One of the main objectives of this project was to determine whether a relationship between transmission and POC, and transmission and TSS existed in the Canada Basin. Our overall attenuation and TSS relationship (Fig. 8 and Table 1, R^2=0.54) was less-correlated than observed in the Gulf Stream and Sargasso Sea (R^2=0.76–0.89; Bishop, 1986), in Puget Sound (R^2=0.78–0.90; Baker and Lavelle, 1984), along the continental rise of the northwest Atlantic (R^2=0.97–0.98; Gardner et al., 1985), in the Equatorial Pacific (R^2=0.60–0.91; Bishop, 1999), and in the Laptev Sea near the Lena River delta (R^2=0.96; Burenkov, 1993). Our attenuation and POC relationship (Fig. 8 and Table 2, R^2=0.48) was less-correlated than observed in the Equatorial Pacific (R^2=0.75–0.95; Bishop, 1999) and sub-arctic Pacific (R^2=0.95; Bishop et al., 1999) when POC was sampled with a Multiple Unit Large Volume in situ Filtration System but better correlated than when POC was sampled in the Equatorial Pacific using rosette bottles (R^2=0.41; Bishop, 1999). In addition, the slope of the line of best fit for our samples was less steep than observed by Bishop (1999) in the Equatorial Pacific, suggesting that the particles in the Canada Basin are both heavier and less efficient at scattering light. We also compared the correlation in 2006 and 2007 and found that in general both TSS (R^2=0.64) and POC (R^2=0.58) were more correlated with attenuation in 2007 than in 2006. The relatively poor correlation in the Canada Basin and its surrounding shelves could be caused by i) scatter due to hydrographic variability (Bishop et al., 1999); ii) the use of rosette bottles instead of large volume pumps to collect POC and TSS samples (Bishop, 1999), although Gardner et al. (2003) suggest the bottle sampling method is better in polar oceans; iii) an inconsistent particle size (Kitchen et al., 1982; Boss et al., 2001; Bowers et al., 2009), particle composition

OSD
7, 1017–1057, 2010

(Kitchen et al., 1982) , or particle density (Bowers et al., 2009); or iv) increased absorption of coloured dissolved organic material in the Arctic Ocean Pegau (2002) compared to other regions, which could affect attenuation.

To determine the effect of hydrographic variability on the relationship between attenuation and TSS and POC concentrations, we separated the data into the five different regions. For TSS, we found that there was significant variability between these regions (Fig. 9, Table 1). Part of this variability was because TSS concentrations were much higher in 2006 than 2007. Overall, the best fits were observed in the western Beaufort shelf in 2006 and in the Northwind Ridge in 2007. The worst fits were seen within the Basin and on the east shelf.

Along the eastern Beaufort shelf, most of the outlier points were observed at 5 m, however, the removal of these points worsened the correlation (R^2=0.13). An assessment of particles measured in sediment traps offshore of the Mackenzie River showed substantial compositional diversity (O'Brien et al., 2005). The transmissometer gives the most accurate readings when the particles are small and have a low density (Bowers et al., 2009) so we suggest that some of the variability in our TSS and attenuation correlation is from inconsistent particle size and composition. Thus, the Mackenzie region is not a good candidate for finding a linear relationship between TSS and attenuation. Along the western Beaufort shelf, the relationship was best in 2006, even in the shallow shelf stations. This suggests that the particles in the western Beaufort shelf are small and of low density and the relationship found in this area can be used to estimate past TSS concentrations. There was significant interannual variability at the Northwind Ridge, with much higher TSS concentrations observed in 2006. However, TSS was well-correlated with attenuation in 2007 when more data points were available. In the interior of the Canada Basin, the outlying points could be placed into 3 groups i) Those with high TSS concentrations and low attenuation. These were found either near the surface in the southern basin or near the bottom; ii) Those with high TSS concentrations and high attenuation. These were found above 20 m in the south-central basin; iii) Those with low TSS concentrations and high attenuation. These were

OSD
7, 1017–1057, 2010

all found at the deep chlorophyll maximum throughout the basin. Similar to Bishop (1999), our results suggest that the transmissometer does not linearly represent suspended particle concentrations and it is likely that the attenuation values depend on the percentage of organic matter. Along the eastern shelf of the basin, we found that there were two types of outlying points i) those with high TSS concentrations and low attenuation, found in water below 100 m.; ii) those with high TSS concentrations and high attenuation, found primarily at 5 m. Unlike within the basin, there were no low TSS, high attenuation particles found within the deep chlorophyll maximum and this is likely because the chlorophyll concentrations were very low here.

We also ran linear regressions to determine the relationship between attenuation and POC within each region (Fig. 10, Table 2). Overall, we found the best relationship within the basin and on Northwind Ridge in 2007, confirming results from Bishop (1999) who found that attenuation was much better correlated with POC than TSS in open ocean areas. POC and attenuation were least correlated along the eastern Beaufort shelf.

An examination of the outliers in the eastern Beaufort shelf found that they were generally from samples that had high TSS concentrations within many different water types. Thus, no consistent relationship between POC and attenuation was found. In the western Beaufort shelf, attenuation and POC were well correlated below an attenuation of 1.1 m^{-1}. When we removed the outlier at attenuation 1.6 m^{-1}, the relationship for both 2006 and 2007 improved to R^2=0.53. Within the basin, we found that many of the outliers were within the upper 20 m, which corresponded to the summer halocline. To examine this relationship, we calculated first the Brunt-Väisälä-frequency as a measurement of stratification (Fig. 11a) and found that several of the high attenuation, low POC points were located within the highly stratified water of the summer halocline. We suggest these particles are deposited in the surface ocean when sea ice melts and are trapped by the strong stratification. Previous studies have found that, although there is considerable variability, most of the particles in sea ice are inorganic (Pfirman et al., 1989; Dethleff et al., 2000). Thus, we calculated the ratio of POC:TSS to confirm that the outliers within the summer halocline also had high TSS concentrations

OSD
7, 1017–1057, 2010

relative to POC (Fig. 11b). Although some particles within the summer halocline had a high POC:TSS ratio, much of the variability can be explained by removing all particles that were found in water with a Brunt-Väisälä-frequency greater than 0.001 s^{-1}. The relationship improved to R^2=0.59. Along the Northwind Ridge, we noticed that there were several samples that had low attenuation and high POC concentrations. Upon closer examination, we found that these POC samples had very high blank values so may have been contaminated in the lab. This contamination would have only affected the three Northwind Ridge stations in 2006. Thus, we decided to base the correlation between POC and attenuation solely on the 2007 relationship. Unlike the stations in the basin, the summer halocline over the Northwind Ridge was not very stratified and there were fewer particles trapped in this layer. This is likely because there was less ice cover here than in the basin region, so there was likely more mixing. Because of this, we decided that the POC-attenuation relationship was suitable for the entire water column. Along the eastern shelf of the Canada Basin, we found that the high attenuation, low POC outlier was found within the nepheloid layer at a depth of 500 m. Since our data show that, unlike the western Beaufort shelf, the nepheloid layer along the eastern shelf has low POC concentrations, we decided to exclude the nepheloid layer from our correlation. We defined the eastern shelf nepheloid layer as water within 50 m of the bottom along the slope (with bottom depths between about 250 and 3000 m) that had attenuation higher than 0.43 m^{-1}. Once this outlier was removed, the relationship improved to R^2=0.60.

We have defined one TSS-attenuation relationship and four POC-attenuation relationship that can be applied to attenuation profiles to estimate past TSS and POC concentrations (Table 3). Upon comparison of the observed to the estimated TSS and POC values, we found that the root mean square error was very high for both TSS and POC in the western Beaufort shelf. This is likely because despite a good linear correlation, the variable particle composition here did not allow for an accurate estimate of TSS and POC values. Thus, we removed the western Beaufort shelf from our interannual comparison. The method error estimates in the Northwind, basin and eastern

OSD
7, 1017–1057, 2010

shelf regions were all within the same order of magnitude of the standard error for POC duplicates (1.6 µg C kg^{-1}).

5 Interannual estimate of POC, summers of 2003 though 2008

5.1 The eastern Northwind Ridge slope region

We calculated the POC concentrations for the Northwind region based on estimates from the POC-attenuation relationships for 2005–2008 (Fig. 12). The summer cruises over the Northwind region sampled both a southern (latitudes 75–76° N) and a northern (latitude 78–78.5° N) section (see Fig. 1) so we contoured these sections separately. To compare the POC values, we divided the water column into three layers – i) The surface from 1–50 m; ii) An intermediate layer from 51–100 m; and iii) Water that was deeper than 100 m – and calculated the average POC concentration within this layer (Table 4). Although some interannual variability was observed above 100 m, the method error for the POC estimate was too high for the differences to be statistically significant.

Above 50 m, we found that the highest average POC values (36 µg C kg^{-1}) were in the southern section in 2006 and the lowest values (20 µg C kg^{-1}) were in the northern section in 2008. In 2006, we also observed very high fluorescence values over the southern Northwind Ridge (Fig. 4), suggesting that much of the POC was phytoplankton. Between 50–100 m, we found that the highest POC values (25 µg C kg^{-1}) were in the southern section in 2006 and 2008 and the lowest values (18 µg C kg^{-1}) were in the northern section in 2006 and 2007. These results suggest in general that the southern Northwind Ridge is more productive than the northern area, which makes sense since the southern region is closer to the Chukchi shelf. In 2006–2008, particles were apparent near the surface that could have been deposited from melting ice. However, unlike the basin region, the summer halocline was weaker here so the particles did not tend to accumulate in the stratification and were spread throughout the upper 25 m. Below 100 m, there was little interannual variability, however, the average particle

OSD
7, 1017–1057, 2010

concentrations here were higher than either the basin interior or eastern shelf regions. This suggests that particles could be transported from the Chukcki Sea to Northwind Ridge in deeper waters, as was suggested by Nishino et al. (2008).

5.2 The interior of the Canada Basin

Jackson et al. (2010) found that the summer halocline was typically located between 10–25 m during the summers of 2003 through 2008. For a more accurate interannual comparison, we chose to estimate the POC within the basin everywhere except from 10–25 m for all years. Most of the variability along 150° N within the Canada Basin was observed within the upper 100 m and near the southern end (Fig. 13). Above 50 m, the POC estimates were greatest in 2003 and lowest in 2008. Much of the high POC seen in 2003 can be attributed to a chlorophyll maximum that was stronger and shallower than other years. From 50–100 m, the highest POC values were found in 2006 an the lowest in 2004. It is interesting that, similar to Tremblay and Gagnon (2010), we observed that the chlorophyll maximum deepened from the summer of 2003 to 2008 (not shown). Thus, with the exception of 2007, the POC concentrations from 50–100 m were slightly higher in latter years. Below 100 m, the average POC values were remarkably consistent with the exception of attenuation features at about 200–400 m at the southern end of the basin in 2005, 2006 and 2008. In these same years, an attenuation feature was observed that extended from the western Beaufort shelf and our results suggest that some of these particles are then transported as far as 74° N.

In the summer of 1994, Wheeler et al. (1997) sampled POC along a transect from the Chukchi Sea to the North Pole. They crossed the Canada, Makarov, Amundsen and Nansen Basins and found that there was an average of 4.6 g C m^{-2} in the upper 100 m. These values were almost 5 times greater than the 1 g C m^{-2} that Kinney et al. (1971) and Gordon and Cranford (1985) found in April and May in the Canada Basin. To compare, we also integrated POC each year in the upper 100 m and, estimated that there was an 2.1 to 2.6 g C m^{-2} in summer in the Canada Basin. These results suggest that our estimate of POC is comparable to previous observed results.

OSD
7, 1017–1057, 2010

5.3 Eastern shelf of the Canada Basin

Attenuation data were collected in the east shelf region only in 2007 so an interannual comparison was not possible. However, our estimate of POC in 2007 suggest that this is the least productive region in our study area. At all stations, the chlorophyll maxima was both deeper and smaller than other areas (Fig. 6). In addition, there appears to be a nepheloid layer that transports primarily inorganic particles into the Canada Basin (Fig. 7).

6 Conclusions

As the Arctic Ocean undergoes rapid change, one of the projected transitions is an increase in suspended particle concentrations (Carmack et al., 2006). For this paper, we examined suspended particle concentrations from both bottle and sensor (transmissometer and fluorometer) data from the summers of 2003 through 2008 to first determine regions of high particle concentrations and then to examine interannual variability.

To account for spatial variability, we divided our study area into five regions – the eastern Beaufort shelf, western Beaufort shelf, eastern Northwind Ridge slope, interior of the Canada Basin, and the eastern shelf of the Canada Basin. We observed the highest attenuation, TSS and POC concentrations along the Beaufort shelf. The eastern Beaufort shelf was characterized by high near-surface particle concentrations that were likely from the Mackenzie river while high particle concentrations along the western Beaufort shelf was more variable, with several attenuation features throughout the water column. There was evidence of significant suspended particle transport from the western Beaufort shelf as far as 74° N in the Canada Basin. Along the Northwind Ridge and within the Canada Basin, we observed that most of the particles were found above 100 m and that the dominant features were i) particles that were trapped within the summer halocline at about 10–20 m and ii) the deep chlorophyll maximum at about 40–60 m. The eastern shelf was the least productive region and had minimal

OSD
7, 1017–1057, 2010

fluorescence and POC values, however, a nepheloid layer at about 400–900 m suggested the transport of particles from shelf into the Canada Basin.

One of the main goals of this paper was to find a relationship between attenuation and bottle data (POC and TSS) that could be applied to past transmissometer data. We found that there was no consistent relationship that could be applied to our entire study region so we again analyzed the five regions separately. In the eastern Beaufort shelf, we found that attenuation was not well-correlated with either POC or TSS and we suggest this is because the transmissometer cannot account for the particle variability in terms of size and density. Along the western Beaufort shelf, both TSS and POC appeared to be well-correlated with attenuation, however, the error measurements were too high to be credible. Along the Northwind Ridge, within the basin and on the eastern shelf, POC and attenuation were well-correlated with the following exceptions – i) Within the summer halocline in the interior of the Canada Basin. Here, it appears that both organic and inorganic particles are being trapped in the strong stratification so POC cannot be accurately estimated; ii) Within the bottom nepheloid layer along the eastern shelf. Again, the particles here are primarily inorganic so POC cannot be estimated.

Once we had determined the relationship between POC and attenuation in the Northwind, basin interior and eastern shelf regions, we estimated POC from the summers of 2003 through 2008 transmissometer data. We found that in all regions, most of the variability was above 100 m and were likely dominated by the strength of the chlorophyll maximum. Below 100 m, there were more particles in the Northwind Ridge region, suggesting the transport of POC from the Chukchi Sea into the western Canada Basin. We found no evidence of increased particle concentrations from the summers of 2003 through 2008, however, it is likely that the this change would occur first near the coast. We think that this work provides a baseline estimate of POC in the Canada Basin to which future changes can be compared.

OSD
7, 1017–1057, 2010

Acknowledgements. Ship based CTD, fluorescence, transmissometer and bottle measurements were supported by the Joint Western Climate Arctic Study (2003–2006) and the Canadian International Polar Year Canada's Three Oceans project (2007–2008). We acknowledge financial and ship time support from Fisheries and Oceans Canada, the National Sciences and Engineering Research Council of Canada, the Northern Scientific Research Program of Canada, Arcticnet network of centres of excellence of Canada, the US National Science Foundation's Beaufort Gyre Exploration Project and collaboration with the Japan Agency for Marine-Earth Science and Technology. We deeply appreciate the assistance and support of the men and women of the Canadian Coast Guard icebreaker Louis S. St. Laurent for collecting CTD and bottle data, chief scientists S. Zimmerman, J. Eert and B. Van Hardenberg, and lab technicians Linda White and Maureen Soon.

References

Ashjian, C. J., Gallager, S. M., and Plourde, S.: Transport of plankton and particles between the Chukchi and Beaufort Seas during summer 2002, described using a Video Plankton Recorder, Deep-Sea Res. Pt. II, 52, 3259–3280, 2005. 1019, 1020, 1025

Baker, E. T. and Lavelle, J. W.: The effect of particle size on the the light attenuation coefficient of natural suspensions, J. Geophys. Res., 89, 8179–8203, 1984. 1020, 1029

Bates, N. R., Hansell, D. A., Moran, S. B., and Codispoti, L. A.: Seasonal and spatial distribution of particulate organic matter (POM) in the Chukchi and Beaufort Seas, Deep-Sea Res. Pt. II, 52, 3324–3343, 2005. 1019, 1025

Bishop, J. K. B.: The correction and suspended particulate matter calibration of Sea Tech transmissometer data, Deep-Sea Res., 33(1), 121–134, 1986. 1020, 1021, 1022, 1029

Bishop, J. K. B.: Transmissometer measurement of POC, Deep-Sea Res. Pt. I, 46, 353–369, 1999. 1020, 1029, 1031, 1052

Bishop, J. K. B., Calvert, S. E., and Soon, M. Y. S.: Spatial and temporal variability of POC in the Northeast Subarctic Pacific, Deep-Sea Res. Pt. II, 46, 2699–2733, 1999. 1020, 1029

Boss, E., Twardowski, M. S., and Herring, S.: Shape of the particulate beam attenuation spectrum and its inversion to obtain the shape of the particulate size distribution, Appl. Optics, 40, 4885–4893, 2001. 1029

OSD

7, 1017–1057, 2010

Suspended particles in the Canada Basin from optical and bottle data

J. M. Jackson et al.

Bowers, D. G., Braithwaite, K. M., Nimmo-Smith, W. A. M., and Graham, G. W.: Light scattering by particles suspended in the sea: The role of particle size and density, Cont. Shelf Res., 29, 1748–1755, 2009. 1029, 1030

Burenkov, V. I.: Optical properties of the Laptev Sea near the Lena River delta, in: Underwater Light Measurements, 2048, edited by: Eilertsen, H. C., The Society of Photo-Optical Instrumentation Engineers Proceedings Series, Bellingham Washington, USA, 175–183, 1993. 1019, 1020, 1029

Carmack, E., Barber, D., Christensen, J., MacDonald, R., Rudels, B., and Sakshaug, E.: Climate variability and physical forcing of the food webs and the carbon budget on panarctic shelves, Prog. Oceanogr., 71, 145–181, 2006. 1018, 1035

Coachman, L. K. and Barnes, C. A.: The contribution of Bering Sea water to the Arctic Ocean, Arctic, 14, 146–161, 1961. 1025

Codispoti, L. A., Flagg, C., Kelly, V., and Swift, J. H.: Hydrographic conditions during the 2002 SBI process experiments, Deep-Sea Res. Pt. I, 52, 3199–3226, 2005. 1019

Darby, D. A.: Sources of sediment found in sea ice from the western Arctic Ocean, new insights into processes of entrainment and drift patterns, J. Geophys. Res., 108, 3257, doi:10.1029/2002JC001350, 2003. 1019

Dethleff, D., Rachold, V., Tintelnot, M., and Antonow, M.: Sea-ice transport of riverine particles from the Laptev Sea to Fram Strait based on clay mineral studies, Int. J. Earth Sci., 89, 496–502, 2000. 1031

Gardner, W. D., Biscaye, P. E., Zaneveld, J. R. V., and Richardson, M. J.: Calibration and comparison of the LDGO nephelometer and the OSU transmissometer on the Nova Scotian Rise, Mar. Geol., 66, 323–344, 1985. 1020, 1029

Gardner, W. D., Richardson, M. J., Carlson, C. A., Hansell, D., and Mishonov, A. V.: Determining true particulate organic carbon: bottles, pumps and methodologies, Deep-Sea Res. Pt. II, 50, 655–674, 2003. 1029

Gordon, D. C. and Cranford, P. J.: Detailed distribution of dissolved and particulate organic matter in the Arctic Ocean and comparison with other ocean regions, Deep-Sea Res., 32(10), 1221–1232, 1985. 1019, 1027, 1034

Guay, C. K. H., McLaughlin, F. A., and Yamamoto-Kawai, M.: Differentiating fluvial components of upper Canada Basin waters on the basis of measurements of dissolved barium combined with other physical and chemical tracers, J. Geophys. Res., 114, C00A09, doi:10.1029/2008JC005099, 2009. 1019

OSD
7, 1017–1057, 2010

Suspended particles in the Canada Basin from optical and bottle data

J. M. Jackson et al.

Hunkins, K., Thorndike, E. M., and Mathieu, G.: Nepheloid Layers and Bottom Currents in the Arctic Ocean, J. Geophys. Res., 74(28), 6995–7008, 1969. 1019, 1021

Jackson, J. M., Carmack, E. C., McLaughlin, F. A., Allen, S. E., and Ingram, R. G.: Identification, characterization and change of the near-surface temperature maximum in the Canada Basin, 1993–2008, J. Geophys. Res., in press, doi:10.1029/2009JC005265, 2010. 1026, 1034

Kinney, P. J., Loder, T. C., and Groves, J.: Particulate and dissolved organic matter in the Amerasian Basin of the Arctic Ocean, Limnol. Oceanogr., 16, 132–137, 1971. 1019, 1027, 1034

Kitchen, J. C., Zaneveld, J. R. V., and Pak, H.: Effect of particle size distribution and chlorophyll content on beam attenuation spectra, Appl. Optics, 21, 3913–3918, 1982. 1029, 1030

Lalande, C., Forest, A., Barber, D. G., Gratton, Y., and Fortier, L.: Variability in the annual cycle of vertical particulate organic carbon export on the Arctic shelves: Contrasting the Laptev Sea, Northern Baffin Bay and the Beaufort Sea, Cont. Shelf Res., 29, 2157–2165, 2009. 1019

Lee, S. H. and Whitledge, T. E.: Primary and new production in the deep Canada Basin during summer 2002, Polar Biol., 28, 190–197, 2005. 1024

Macdonald, R. W., Solomon, S. M., Cranston, R. E., Welch, H. E., Yunker, M. B., and Gobeil, C.: A sediment and organic carbon budget for the Canadian Beaufort Shelf, Mar. Geol., 144, 255–273, 1998. 1019

Mathis, J. T., Pickart, R. S., Hansell, D. A., Kadko, D., and Bates, N. R.: Eddy transport of organic carbon and nutrients from the Chukchi Shelf: Impact on the upper halocline of the western Arctic Ocean, J. Geophys. Res., 112, C05011, doi:10.1029/2006JC003899, 2007. 1020

McLaughlin, F. A., Carmack, E. C., Zimmerman, S., Sieberg, D., White, L., Barwell-Clarke, J., Steel, M., and Li, W. K. W.: Physical and chemical data from the Canada Basin, August, 2004, Can. Data Rep. Hydrog. Ocean Sci., 140, 185 pp., 2008. 1020

Nishino, S., Itoh, M., Yamamoto-Kawai, M., and Chiba, S.: East-west differences in water mass, nutrient, and chlorophyll-*a* distributions in the sea ice reduction region of the western Arctic Ocean, J. Geophys. Res., 113, C00A01, doi:10.1029/2007JC004666, 2008. 1024, 1034

O'Brien, M. C., Macdonald, R. W., Melling, H., and Iseki, K.: Particle fluxes and geochemistry on the Canadian Beaufort Shelf: Implications for sediment transport and deposition, Cont. Shelf Res., 26, 41–81, 2005. 1019, 1024, 1030

Pegau, W. S.: Inherent optical properties of the central Arctic surface waters, J. Geophys. Res., 107, 8035, doi:10.1029/2000JC000382, 2002. 1030

Pfirman, S., Gascard, J. C., Wollenburg, I., Mudie, P., and Abelmann, A.: Particle-laden Eurasian Arctic sea ice: Observations from July and August 1987, Polar Res., 7, 59–66, 1989. 1031

Pickart, R. S.: Shelfbreak circulation in the Alaskan Beaufort Sea: Mean structure and variability, J. Geophys. Res., 109, C04024, doi:10.1029/2003JC001912, 2004. 1025

Proshutinsky, A., Krishfield, R., Timmermans, M.-L., Toole, J., Carmack, E., McLaughlin, F., Williams, W. J., Zimmerman, S., Itoh, M., and Shimada, K.: Beaufort Gyre freshwater reservoir: State and variability from observations, J. Geophys. Res., 114, C00A10, doi:10.1029/2008JC005104, 2009. 1024

Tremblay, J.-E. and Gagnon, J.: The effects of irradiance and nutrient supply on the productivity of Arctic waters: a perspective on climate change, Influence of climate change on the changing Arctic and Subarctic conditions, in: NATO Science for Peace and Security Series-C: Environmental Security, edited by: Nihoul, J. C. J. and Kostianoy, A. G., accepted, 73–93, 2010. 1024, 1034

Wheeler, P. A., Gosselin, M., Sherr, E., Thibault, D., Kirchman, D. L., Benner, R., and Whitledge, T. E.: Active cycling of organic carbon in the central Arctic Ocean, Nature, 380, 697–699, 1996. 1019

Wheeler, P. A., Watkins, J. M., and Hansing, R. L.: Nutrients, organic carbon and organic nitrogen in the upper water column of the Arctic Ocean: implications for the sources of dissolved organic carbon, Deep-Sea Res. Pt. II, 44(8), 1571–1592, 1997. 1019, 1034

Yamamoto-Kawai, M., McLaughlin, F.A, Carmack, E. C., Nishino, S., Shimada, K., and Kurita, N.: Surface freshening of the Canada Basin, 2003–2007: River runoff versus sea ice meltwater, J. Geophys. Res., 114, C00A05, doi:10.1029/2008JC005000, 2009. 1019, 1024, 1026

OSD
7, 1017–1057, 2010

Table 1. A comparison of the relationships between beam attenuation coefficient and total suspended solids. The symbol n represents the number of samples in each linear regression. The units for slope and intercept are m^{-1} µg kg^{-1}.

Region	year	n	slope ($\times 10^{-3}$)	intercept	R^2
all	2006	62	0.347	0.35	0.44
	2007	130	0.434	0.39	0.64
	2006, 2007	295	0.318	0.39	0.54
Eastern Beaufort	2006	26	0.147	0.42	0.13
	2007	22	0.517	0.39	0.47
	2006, 2007	48	0.153	0.41	0.23
Western Beaufort	2006	21	0.496	0.34	0.75
	2007	20	0.425	0.40	0.56
	2006, 2007	41	0.468	0.38	0.75
Northwind Ridge	2006	6	0.350	0.28	0.39
	2007	19	0.453	0.38	0.74
	2006, 2007	25	0.143	0.40	0.36
Canada Basin	2006	9	0.035	0.44	0.02
	2007	35	0.050	0.41	0.02
	2006, 2007	44	0.087	0.41	0.14
East shelf	2007	33	0.044	0.40	0.03

Table 2. A comparison of the relationships between beam attenuation coefficient and particulate organic carbon. The symbol n represents the number of samples in each linear regression. The units for slope and intercept are m^{-1} µg C kg^{-1}.

Region	year	n	slope ($\times 10^{-2}$)	intercept	R^2
all	2006	174	0.341	0.38	0.45
	2007	121	0.272	0.37	0.58
	2006, 2007	295	0.335	0.37	0.48
Eastern Beaufort	2006	63	0.235	0.41	0.11
	2007	23	0.216	0.38	0.30
	2006, 2007	86	0.238	0.40	0.12
Western Beaufort	2006	37	0.320	0.43	0.44
	2007	20	0.254	0.41	0.46
	2006, 2007	57	0.314	0.46	0.41
Northwind Ridge	2006	27	0.152	0.37	0.37
	2007	20	0.19	0.38	0.59
	2006, 2007	47	0.14	0.38	0.39
Canada Basin	2006	47	0.142	0.39	0.32
	2007	29	0.206	0.38	0.75
	2006, 2007	76	0.152	0.39	0.37
East shelf	2007	32	0.166	0.38	0.52

OSD
7, 1017–1057, 2010

Table 3. TSS-attenuation and POC-attenuation statistics for regions that had good relationships (R^2 value greater than 0.50 for all samples) between the bottle and sensor data. The symbols WBS stand for western Beaufort shelf, NWR for Northwind Ridge, CB for the interior of the Canada Basin, ESCB for the eastern shelf of the Canada Basin and BV the Brunt-Väisälä frequency. Units are $m^{-1}\,\mu g\,kg^{-1}$ for TSS slope, $m^{-1}\,\mu g\,C\,kg^{-1}$ for POC slope, $\mu g\,kg^{-1}$ for TSS intercept and $\mu g\,C\,kg^{-1}$ for POC intercept.

Particles	Region	Slope	Intercept	R^2	RMSE	Comments
TSS	WBS	1595	−472	0.75	233	
POC	WBS	188	−55	0.53	33.1	For attenuation<1.1 m^{-1}
POC	NWR	306	−108	0.59	8.3	
POC	CB	410	−153	0.59	6.1	For water with BV<0.001 s^{-1}
POC	ESCB	378	−140	0.60	4.1	Not for nepheloid layers

OSD
7, 1017–1057, 2010

Suspended particles in the Canada Basin from optical and bottle data

J. M. Jackson et al.

Table 4. An interannual comparison from the summer of 2003 to the summer of 2008 of the estimated averages of POC per meter (in µg C kg^{-1} m^{-1} with standard error) within different regions in the upper 50 m, from 50 m to 100 m and below 100 m. The dash represents years when no attenuation data were available. The symbol NWR represents the Northwind Ridge region, CB the interior of the Canada Basin and ESCB the eastern shelf of the Canada Basin. The numbers underneath the region name is the method error based on the root mean square error. Note that the method error is always greater than the standard error of the average estimated POC concentration.

Region	Depth	2003	2004	2005	2006	2007	2008
NWR	1–50 m	–	–	30±0.4	28±0.8	25±0.4	22±0.3
	51–100 m	–	–	20±0.4	21±0.4	19±0.3	23±0.6
±8.1	>100 m	–	–	12±0.0	13±0.0	12±0.0	13±0.0
CB	1–9 m and 26–50 m	37±1.5	28±0.9	31±1.0	27±3.6	25±0.7	22±0.8
	51–100 m	19±0.4	17±0.4	21±0.5	22±0.7	18±0.5	20±0.4
±6.1	>100 m	8±0.0	7±0.0	7±0.0	7±0.0	7±0.0	7±0.0
ESCB	1–50 m	–	–	–	–	16±0.3	–
	51–100 m	–	–	–	–	14±0.1	–
±4.1	>100 m	–	–	–	–	9±0.0	–

Discussion Paper | Discussion Paper | Discussion Paper | Discussion Paper |

OSD

7, 1017–1057, 2010

Suspended particles in the Canada Basin from optical and bottle data

J. M. Jackson et al.

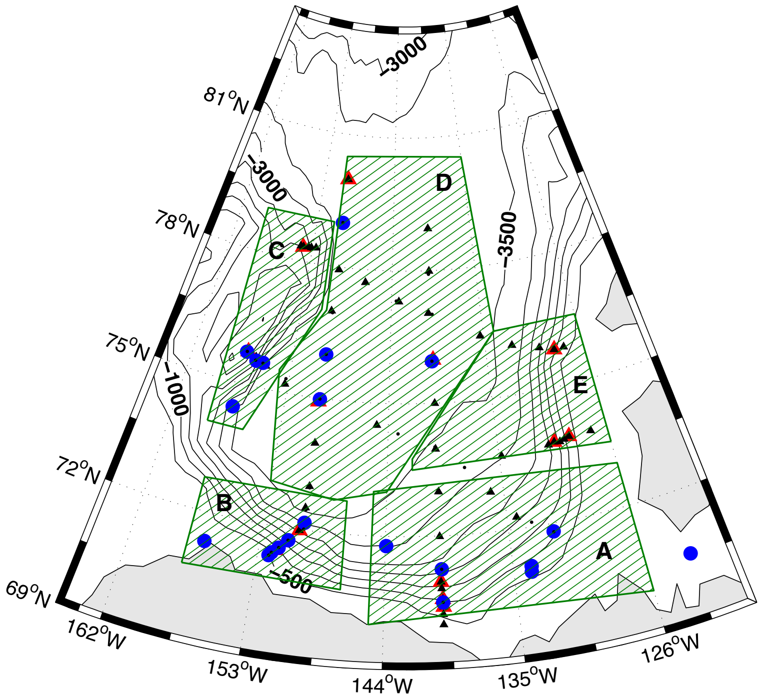

Fig. 1. Bathymetric map of the stations where POC and TSS were sampled in 2006 (blue circles) and 2007 (red triangles). Contoured depths are labeled in meters at 500 m intervals. Small black circles (2006) and triangles (2007) represent stations where the CTD and sensors were deployed but no POC or TSS were sampled. This study area was separated into 5 regions over which the POC and TSS was averaged at each sampling level. These are A) the eastern Beaufort shelf that includes the Mackenzie Trough, B) the western Beaufort shelf that includes the Barrow Canyon, C) the eastern Northwind Ridge slope, D) the interior of the Canada Basin, and E) the eastern Canada Basin shelf between Banks Island and Prince Patrick Island.

OSD

7, 1017–1057, 2010

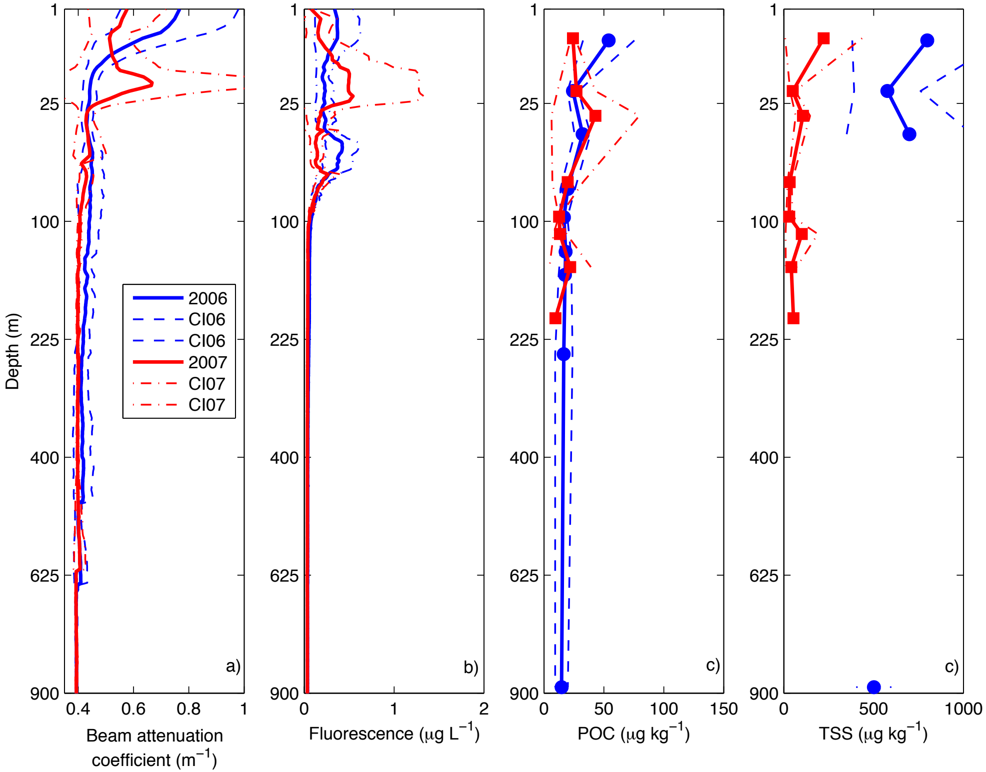

Fig. 2. Average profiles of **(a)** beam attenuation coefficient, **(b)** fluorescence, **(c)** POC, and **(d)** TSS in the eastern Beaufort shelf region for 2006 (blue lines) and 2007 (red lines). The vertical axis is the square root of depth to emphasize the near-surface features. The red and blue dashed lines represent the 95% confidence intervals for 2006 and 2007, respectively. For beam attenuation coefficient only, the 5 m centred running mean was plotted to smooth the data. The blue circles and red squares represent the average sampling depth for POC and TSS in 2006 and 2007, respectively.

OSD
7, 1017–1057, 2010

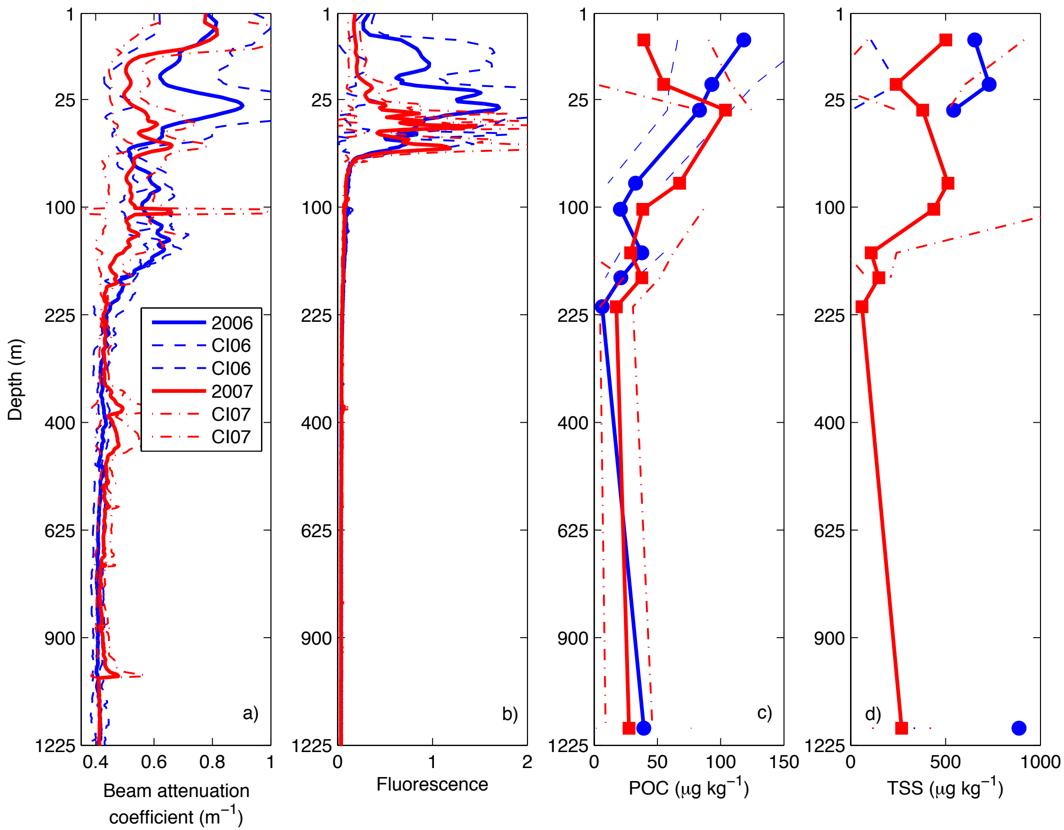

Fig. 3. As in Fig. 2 but for the western Beaufort shelf region.

OSD

7, 1017–1057, 2010

Suspended particles in the Canada Basin from optical and bottle data

J. M. Jackson et al.

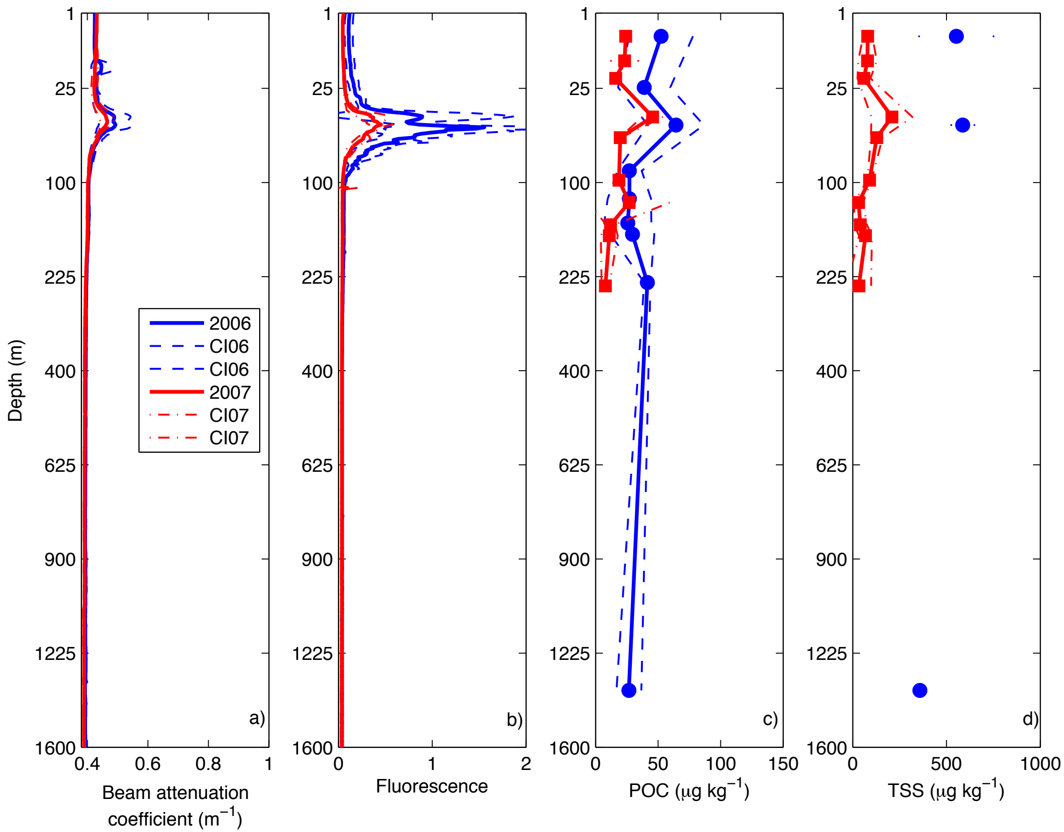

Fig. 4. As in Fig. 2 but for the eastern Northwind Ridge slope region.

OSD
7, 1017–1057, 2010

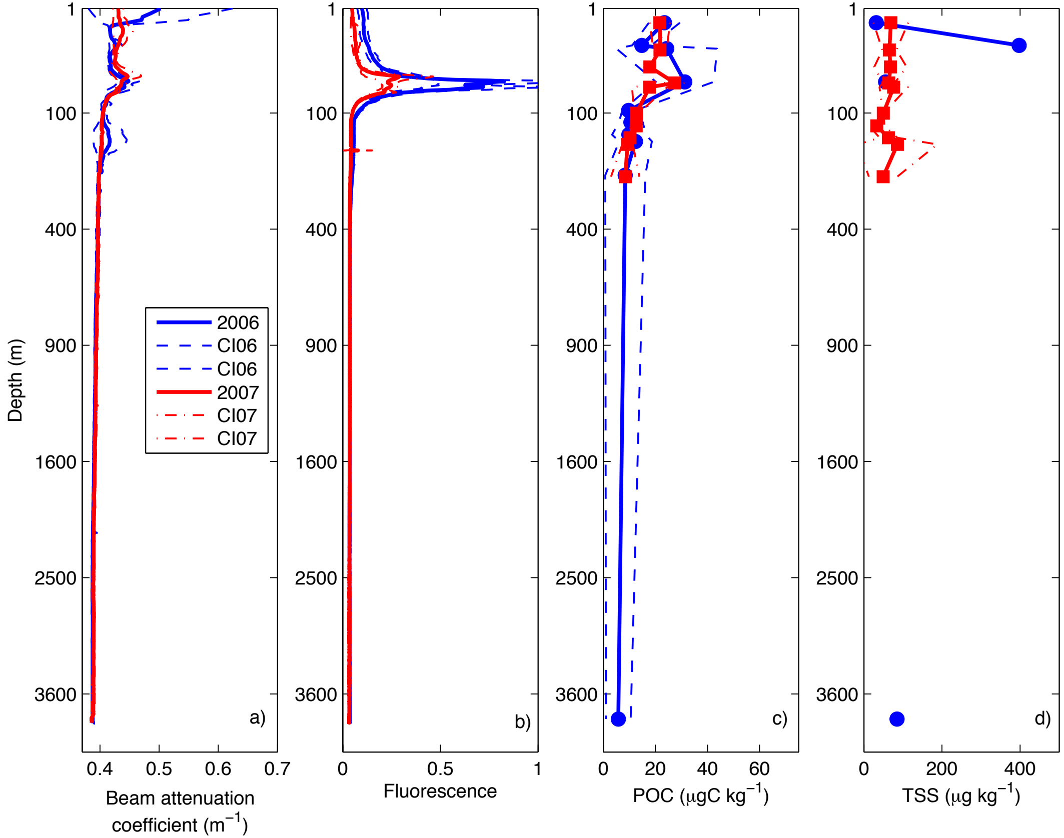

Fig. 5. As in Fig. 2 but for the interior of the Canada Basin. The values on the horizontal axes are half of those in Figs. 2–4.

OSD
7, 1017–1057, 2010

Suspended particles in the Canada Basin from optical and bottle data

J. M. Jackson et al.

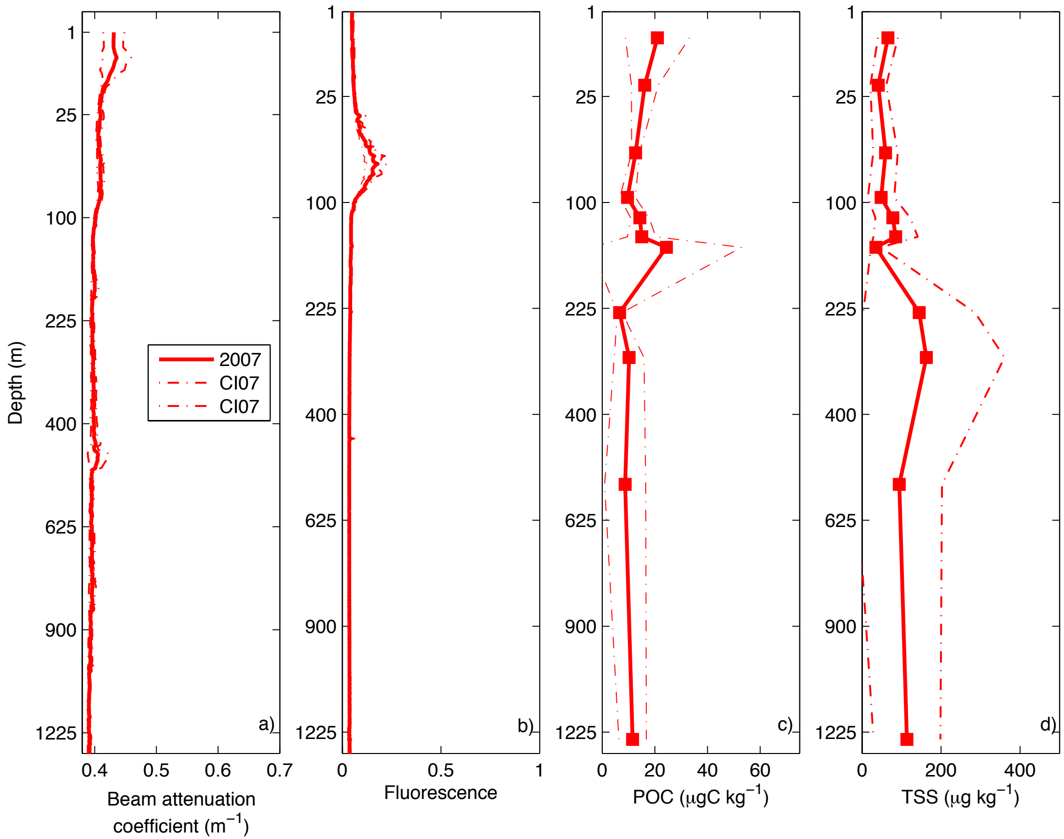

Fig. 6. As in Fig. 2 but for the eastern Canada Basin shelf region. This region was sampled only in 2007. The values on the horizontal axes are half of those in Figs. 2–4.

OSD
7, 1017–1057, 2010

Suspended particles in the Canada Basin from optical and bottle data

J. M. Jackson et al.

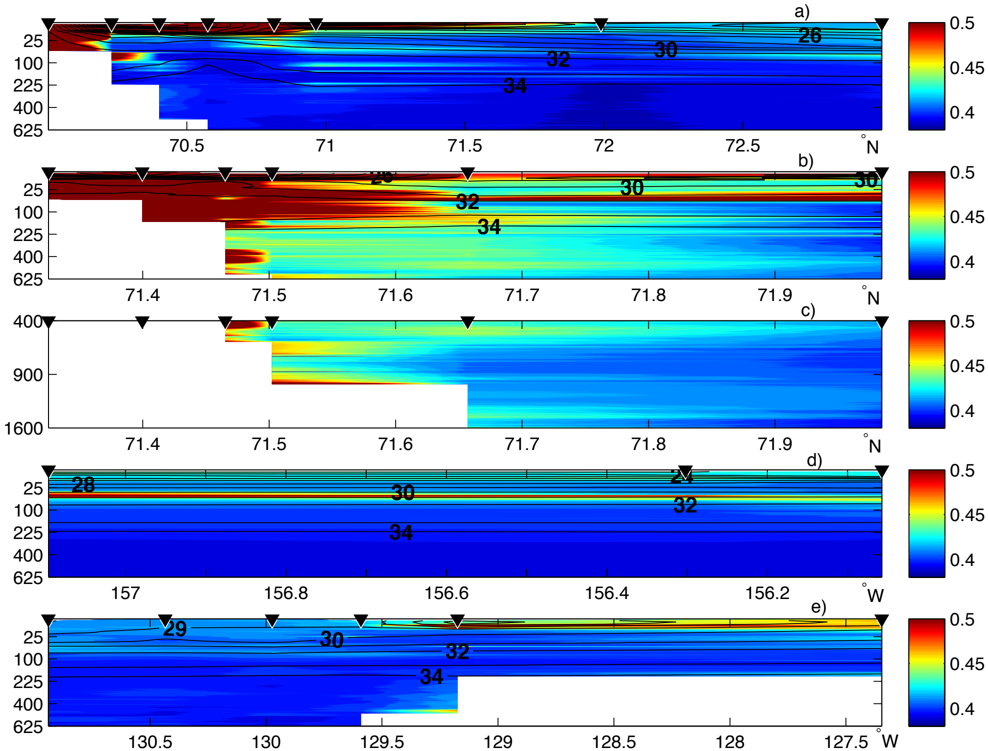

Fig. 7. A comparison of the beam attenuation coefficient (m^{-1}) along four different shelf-basin sections. These are **(a)** the eastern Beaufort shelf region along the longitude 140° W, **(b)** the western Beaufort shelf region along the longitude 150–152° W. Here, the near-surface (1–625 m) attenuation features are shown **(c)** The deep attenuation features (400–1600 m) along the western Beaufort shelf, **(d)** The eastern Northwind Ridge slope region along the latitude 75–76° N, and d) the eastern shelf of the Canada Basin region along the latitude 73–74° N. The vertical axis is the square root of depth. Black horizontal lines represent the isohalines with 1.0 salinity resolution and black triangles denote the station locations.

OSD
7, 1017–1057, 2010

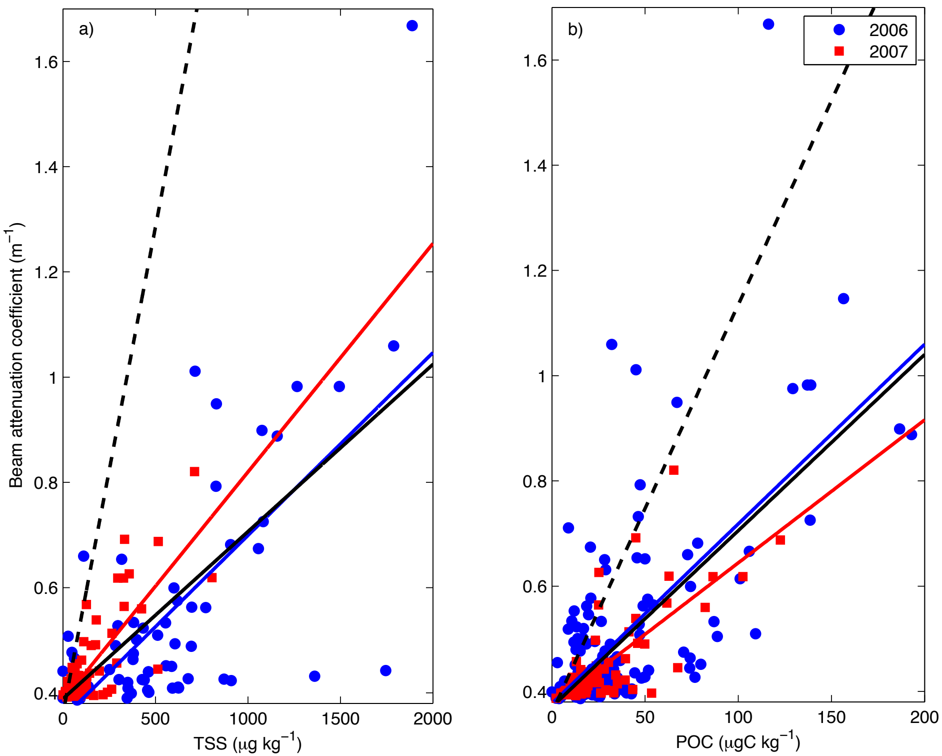

Fig. 8. Linear least squares regression of **(a)** the relationship between beam attenuation coefficient and total suspended solids, and **(b)** the relationship between beam attenuation coefficient and particulate organic carbon. The blue dots represent samples taken in 2006 and the red squares are samples taken in 2007. The blue and red lines represent the line of best fit for 2006 and 2007, respectively. The solid black line represents the line of best fit from both years together and the dashed black line represents the linear regression (bac=0.00755(POC)+0.36 and bac=0.00185(TSS)+0.36) from Bishop (1999) based on JGOFS Equatorial Pacific data.

OSD
7, 1017–1057, 2010

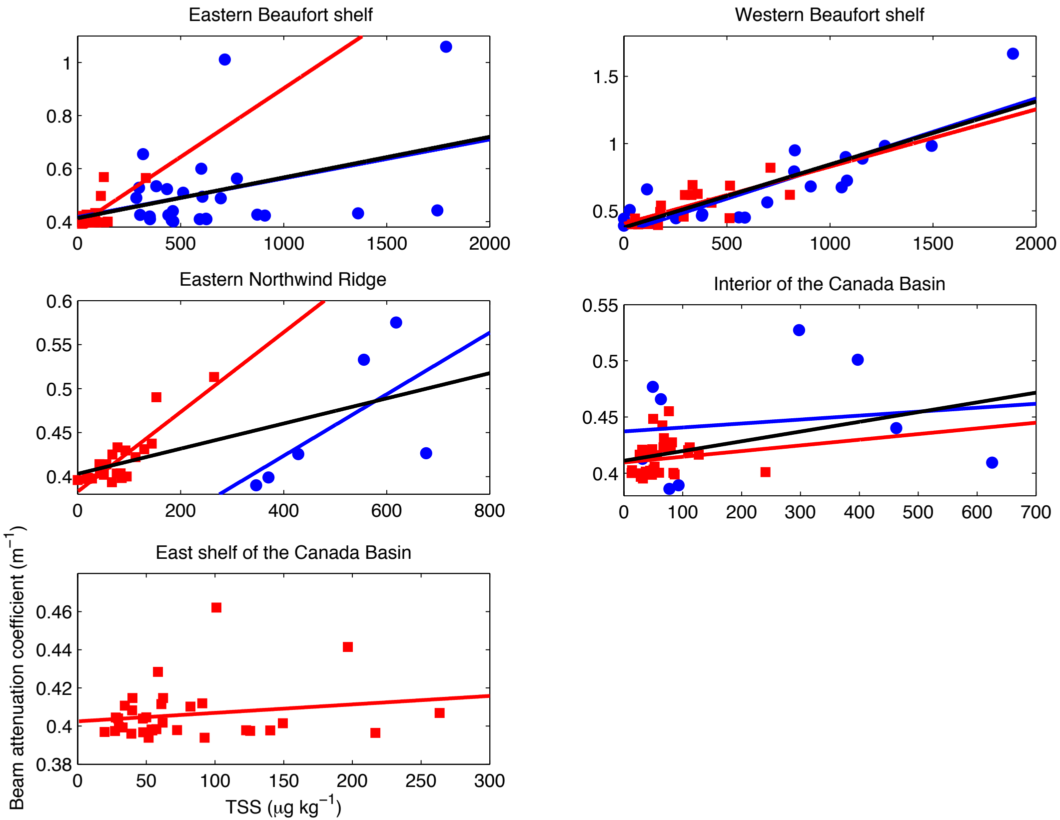

Fig. 9. Linear regression of the relationship between beam attenuation coefficient and total suspended solids (µg kg^{-1}) in the five different regions. Here, the blue circles are samples from 2006 and the red squares are from 2007. The lines denote the linear least square regression from 2006 (blue lines), 2007 (red lines) and both 2006 and 2007 (black lines). Linear relations and R^2 values are listed in Table 1. Note that the scales are different in each figure.

OSD
7, 1017–1057, 2010

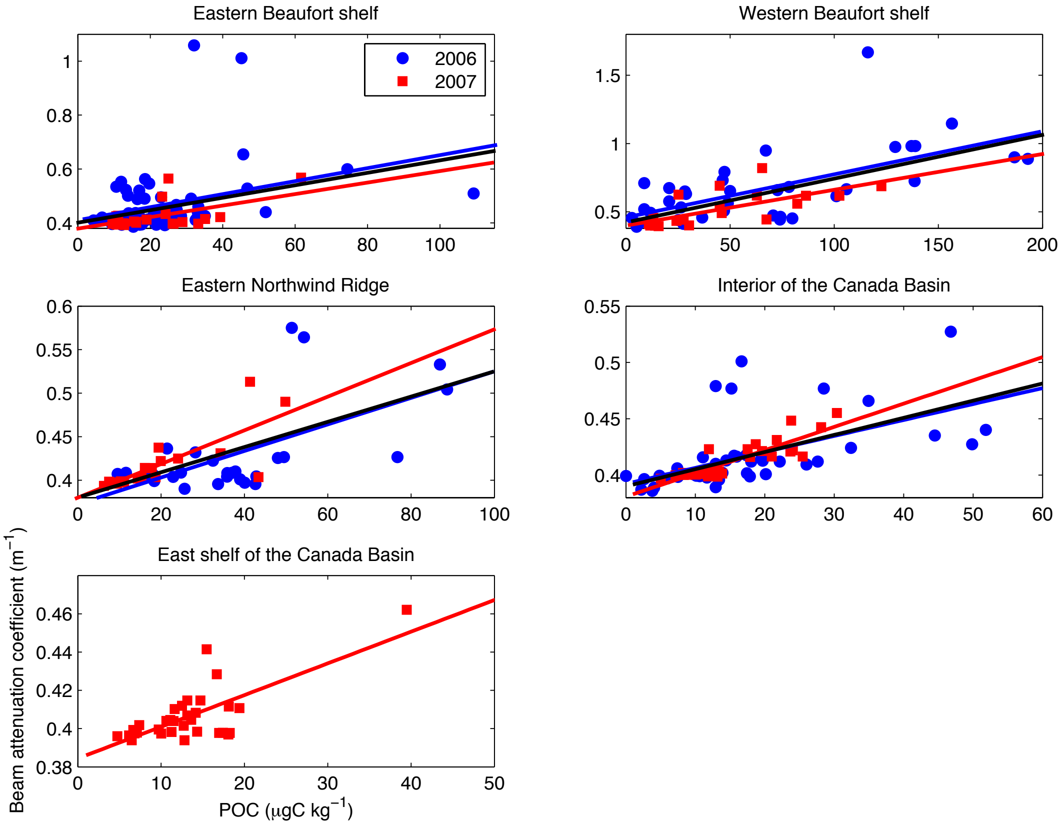

Fig. 10. As in Fig. 9 but for correlations between attenuation and POC. Linear relations and R^2 values are listed in Table 2. Note that the scales are different in each figure.

OSD
7, 1017–1057, 2010

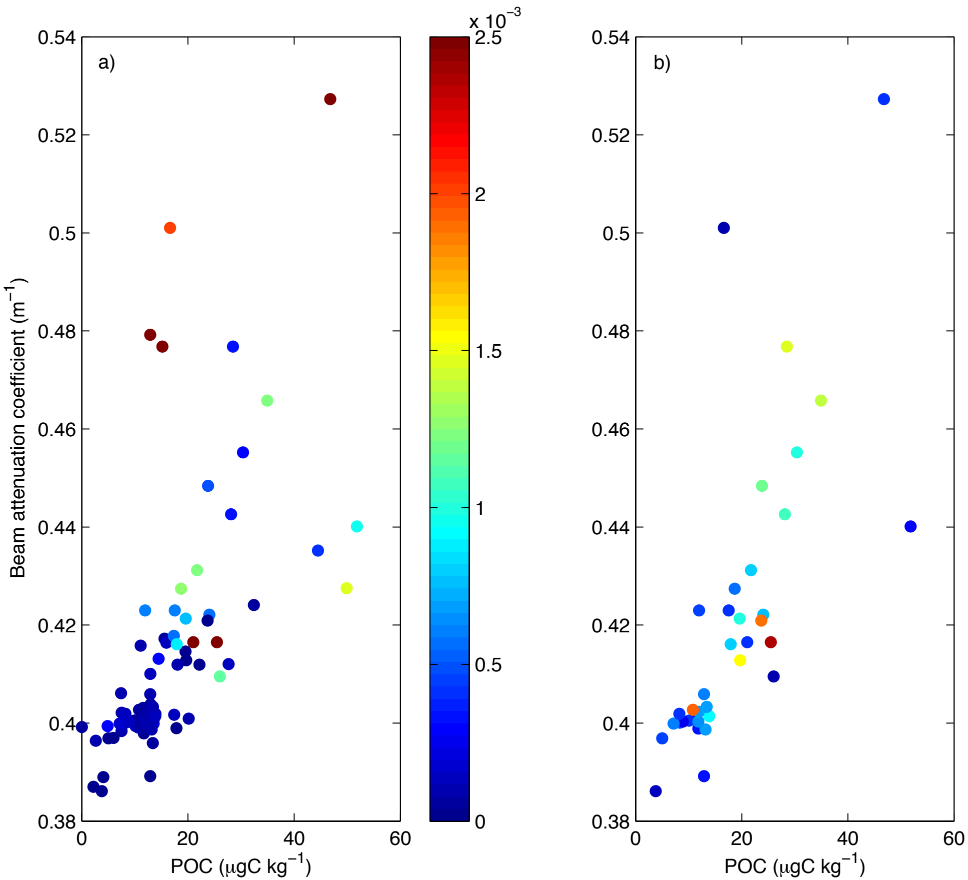

Fig. 11. Relationship for the station within the interior of the Canada Basin between **(a)** attenuation, POC and the Brunt-Väisälä-frequency (s^{-1}) and **(b)** attenuation, POC and the ratio of POC to TSS. There are fewer points in plot (b) because TSS was sparsely sampled in 2006.

OSD
7, 1017–1057, 2010

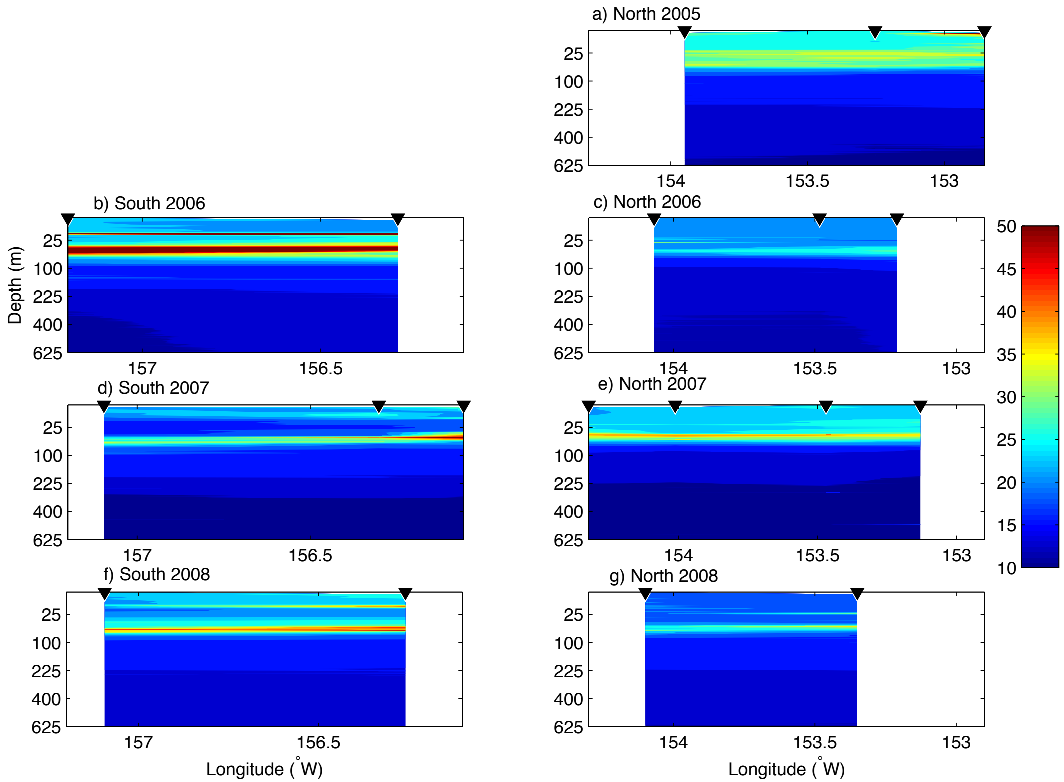

Fig. 12. Estimated values of POC (µg C kg^{-1}) for the eastern Northwind Ridge slope. This region was sampled along a southern line (latitudes 75–75° N) and along a northern line (latitudes 78–79° N). Here, the northern line is shown on the right for **(a)** 2005, **(c)** 2006, **(e)** 2007, and **(g)** 2008 and the southern line is shown on the left for **(b)** 2006, **(d)** 2007, and **(f)** 2008. Only one station was sampled along each line in 2003, 2004 and the southern region in 2005. The black triangles denote the station location.

OSD
7, 1017–1057, 2010

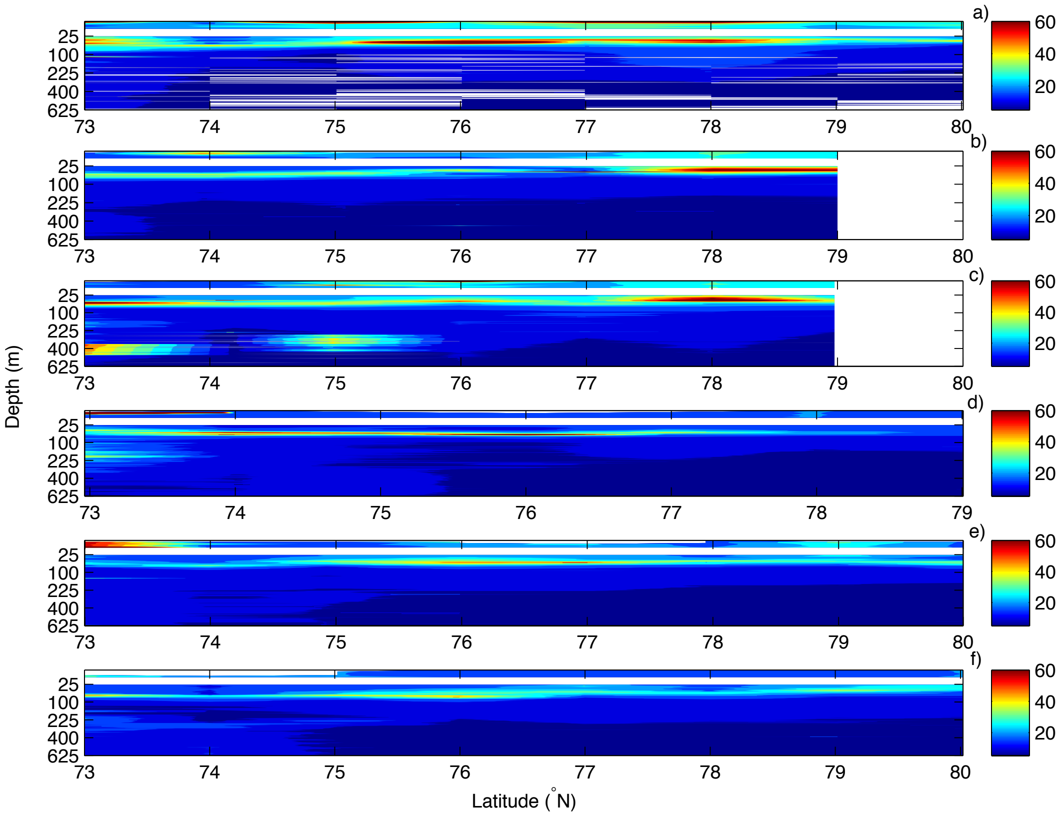

Fig. 13. Estimated values of POC (µg C kg^{-1}) in the interior of the Canada Basin along longitude 150° W. POC was estimated for **(a)** 2003, **(b)** 2004, **(c)** 2005, **(d)** 2006, **(e)** 2007 and **(f)** 2008. Station locations were at 1° intervals for each year.