RESPONSES to the review of the manuscript:

"Patterns of suspended particulate matter across the continental margin in the Canadian Beaufort Sea", Jens K. Ehn, Rick A. Reynolds, Dariusz Stramski, David Doxaran, Bruno Lansard, and Marcel Babin

We greatly appreciate the constructive comments from both reviewers. Here we provide our detailed point-by-point responses and any description of action taken in regards to the comments by Referee #1. The Referees' comments are shown in regular font; our responses follow each comment in blue font.

Response to Referee #1

General comments

The present manuscript reports on the distribution and patterns of suspended particulate matter (SPM) and associated optical properties in the Canadian Beaufort Sea. Specifically, the authors demonstrate the correlation between the particulate beam attenuation and the dry mass concentration of SPM and use it to extend the SPM data to stations where only beam attenuation measurements were done. The obtained SPM distribution is discussed in relationship with environmental forcing such as wind, river discharge and sea ice coverage. The authors show that these forcings result in different circulation modes, upwelling onto the shelf, downwelling return flow across the shelf and vertical mixing due to strong wind conditions.

The manuscript is clearly written, the methods well explained and the graphs mostly illustrate the data accordingly.
My major concern about this manuscript relates to its structure. The authors present in a first step the optical (beam attenuation) and SPM data obtained during MALINA 2009 cruise and use these data to develop the SPM algorithm. The algorithm is then applied to beam attenuation data obtained from 4 other cruises in the Canadian Beaufort Sea, in order to extend the SPM data set. The second step consists in presenting almost a new manuscript with a first description of environmental parameters and then of different patterns of SPM distribution.

Although the presented structure is clear, the different pieces (paragraphs) are rather isolated and their contribution to the scientific question remains unclear.
I would therefore propose a different approach, which consists in keeping the first part with the MALINA data and use the data of the second part to do a statistical analysis relating the SPM patterns to the different environmental scenarios. Not only would the findings be more robust by being "statistically" supported compared to the only descriptive presentation in the present manuscript, but also the manuscript as a whole would appear more coherent with respect to SPM patterns related to environmental forcing.

I will give more detailed arguments in the specific comments in order to better explain my proposition.

REPLY: We would like to thank Referee #1 for the insightful comments that spurred us to take a critical look at the structure of our manuscript. We agree mostly with the revisions that have been suggested by Referee #1. We agree that the link between the SPM algorithm development using MALINA data and the second part that involved comparisons to forcing conditions required clarifications. In the revised manuscript, we have put much effort into focusing the paper by rearranging its structure and removing unnecessary descriptions. However, considering unavoidable limitations in the available data sets, the possibility of conducting a statistical analysis of the kind suggested by Referee #1 appeared to us highly problematic. Instead of attempting such statistical analysis, we have followed the advice of Referee #2 and increased a focus of the manuscript on particle characteristics associated with freshwater inputs. This involved including a new data set of water oxygen isotopic composition. See also our reply to the comment on Paragraph 3.3.

Regarding the lack of exploitation of the effects of particle size and composition on the SPM vs. cp relationship, we point out that we have to rely on one relationship regardless of particle size and composition because we apply the relationship to the cp data measured during different field experiments when no ancillary data on particle size and composition were available. In contrast to cp, which is routinely collected in the field as a part of CTD casts, the particle size and composition data are rarely collected except during focused/dedicated field experiments. Thus, in this paper we use the particle size and composition data gathered on MALINA primarily to indicate that our relationships between cp, SPM, and POC are robust over a broad range of variability in the particle assemblage.

Given the quite extensive scope of revisions that we made with regard to restructuring the mansucript and making changes in the content of various sections, it would be impractical to describe each and every change related to the restructuring in this response. We believe, however, that these main changes are easily identifiable in the revised manuscript.

Specific comments

Introduction: The scientific context is well presented. Particle origin and transport ways, as well as the different factors to which beam attenuation is sensitive (concentration, size and composition of particles) are introduced, and one would expect that these factors would be discussed accordingly within the manuscript. Even if at the end of the introduction, the authors solely talk about particles, the reader would suppose that they mean organic and mineral but also different sizes of particles. Also, clearly, the authors admit temporal variations of particle characteristics but intend to relate the distribution patterns to oceanographic conditions (last sentence of the introduction).
This is exactly what could be answered by my above proposition: A robust, statistical relationship between environmental parameters and particle distribution takes into account the different variabilities and overcomes at least at a certain probability level such uncertainties.

REPLY: To improve the description of the effects of different factors on beam attenuation we included a more detailed description in paragraph 3 of the Introduction section. Earlier this text was part of the first paragraph of the original section 3.1.2, now 3.2.2, which has now been shortened. As mentioned above, with regard to statistical analysis, we have followed the advice of Referee #2 and increased a focus of the manuscript on particle characteristics associated with freshwater inputs. We believe this is an important aspect which improved the manuscript. See also our reply to the comment on Paragraph 3.3.

Paragraph 3.1.2.: The paragraph could be removed and the beam attenuation results presented together with the data from the other cruises.

The fluorescence is certainly an important parameter for the particle characteristics, but the authors do not discuss these data (paragraph 3.4.5.) very extensively. E.g. they could use them to see how autochthonous production of particles and the related difference in distribution dynamics influences the general particle distribution pattern. Also, there is no discussion on its influence on the beam attenuation data, although the authors clearly state it (line 30, page 7).

REPLY: We have considerably rearranged this part of the text. The original sections 3.1.2 and 3.1.3 have been combined into a new section 3.2. The new sections 3.1 and 3.2 still focus on MALINA observations to show the ranges in water and particle characteristics, which underlie the development of statistical relationships presented in the section 3.3. Measurements of chl-a fluorescence are used throughout the revised manuscript (e.g., sections 3.2, 3.4) as an indicator of particle origin and characteristics.

Paragraph 3.1.3.: As said before, several characteristics of particles that influence the beam attenuation are presented, but this aspect is not really included in later discussions.
Some interesting findings are presented about mineral and organic dominated particle composition, but none of this is being considered when it comes to a general discussion on the particle distribution patterns, unless I have overseen this point.

Routine beam attenuation measurements during the Arctic expeditions used in our analyses have not been accompanied with specialized analysis aimed at determining the particle composition and PSD characteristics (with the exception of a subset of MALINA data set). Because of this lack, we feel that speculations regarding the potential effects of particle assemblage properties (such as composition and PSD) on the discussion of general SPM patterns is unwarranted in the context of these additional cruises. The subset of MALINA data is used to indicate that our developed relationships are applicable over a wide range of variability in the particle assemblage.

The same accounts for the particle volume distribution and the particle size distribution (PSD). The data of the former are not so much of a surprise to me and I do not think that they contribute substantially to the science of this manuscript. However, the data about PSD deserve more attention than given by the authors. The description (lines 1-6, page 9) is rather confusing and a table or a graph would shed much more light on them. Also, the authors could use these data to discuss points like optical properties of different size spectra, is the chosen wavelength (660 nm) appropriate for all types of spectra etc. Some of the co-authors (Reynolds, Stramski) have signed a very nice article in L&O, 61, 2016, which I would consider as a model case of thorough discussion related to the same subject. I could imagine that this opens many possibilities of parameters to be used for statistical treatment.

REPLY: We have included a reference to Reynolds et al. (2016) and indicated that this study includes a detailed discussion of the PSD data collected in Arctic waters, including results from MALINA. In the revisions we have focused on improving the presentation of the relationship between the particle composition and size characteristics and freshwater composition. In Fig. 5 (formerly Fig. 4) we have added two graphs illustrating how POC/SPM and PSD shape are related to meteoric water fractions present in surface water samples. In our view, these revisions address the points made above and focus the discussion on differentiating particle characteristics between sources (fluvial, sea ice melt, and pelagic).

Paragraph 3.2.: The relationships and different regressions are presented in much detail. While some of them are not necessary, others add more confusion than clarity. E.g. what do the two measurements, RMSE and MNB, add to the regression coefficient? The latter is rather well known, but the former may need some explanation in order to be evaluated by the reader, e.g. reference values for the two (0, 1) would permit an evaluation of the presented results.

The explanation of the regressions of the c_p (660) and c_p (676) vs. SPM data (lines 18-24, page 10) are confusing. It is not clear which points were used for the two analyses, red points for red regression? but red stands also for mineral-dominated, i.e. are there only mineral dominated data for 676 nm measurements? In this case, it is maybe worth to explore if the measurements for the two wavelengths can be merged, which would at the same time better justify the argument that equation 2) is used for high SPM values (lines 21,22, page 10).

Lines 20-23, page 9: If differences in r^2 are not significant, there should be a better argument than just “appears to best match” for choosing a linear power function fit, unless the RMSE and MNB measures are better explained.
In the same sense, what conclusion can be drawn from the fact that a non-linear power function fit is best for SPM data and a linear regression to log-transformed data best for POC data? This brings me to a general question about establishing relationships between optical and biological measurements. Is it possible to attribute some functional meaning to a given class of data fits? For example, if the fit is a power function, is this related to growth rates of phytoplankton and if it is a linear fit, is it related to cell density etc.?

REPLY: In response to these comment and to clarify the issues related to regression analysis, we have moved the detailed description of the regression fits to the Supplementary Materials, where we also provide the RMSE and MNB equations. In the revised manuscript only the two final chosen regressions are shown, which are then applied to beam attenuation data from the three Arctic expeditions. We have also made it clear that all data points, regardless of their “colour”, are used in the final regression fits. For more details about the regression analysis, the readers are referred to the Supplementary Materials. This additional material also includes results for different types of regression fits. With the regards to functional meaning, we point out that the various models (linear, power) were not statistically different, and we chose the power function as this has been the most common approach used in the past. These are simply empirical best-fits to the relationship.

Paragraphs 3.3. and further: It appears as if the SPM data from the other cruises are used to discuss the patterns from MALINA by choosing the contrasting or similar situations. Examples: 1) Wedges of clear water found over the shelf due to near meltwater from extensive ice

coverage, as opposed to low ice coverage in other cruises where clear water is absent (paragraph 3.4.1.).
2) High near bottom SPM concentration during MALINA related to downwelling return flow as opposed to 2008 upwelling situation with high river plume extension and low bottom SPM concentration (paragraph 3.4.2.).
3) Similar SPM patterns between MALINA and CASES 2004, but higher SPM concentration during CASES due to timing of the year (recent break up of land fast ice cover) (paragraph 3.4.3.).
These examples together with the points discussed in paragraphs 3.4.4. (high SPM concentrations in a well-mixed water column due to upwelling) and 3.4.5 (primary production depends on sea ice coverage (light availability), nutrient availability and river plume extension related to wind conditions) are all criteria which could be generalized and chosen as parameters for a statistical analysis to explore relationships between the main environmental factors sea ice coverage, river discharge and wind and the typical patterns of SPM distribution quantified by the dry mass concentration of SPM across the shelf and into the Canada Basin.
Since the descriptions given in these paragraphs are rather clear, I could well imagine that a statistical analysis will yield significant results, which is in my view the ideal way to apply statistical analyses to environmental data: First, you inspect the data in a rather subjective manner, then you are able to apply the appropriate statistical analysis to obtain an objective result with a given amount of error.

REPLY: We agree that a statistical analysis would be ideal, however, it is unclear to us how to implement a statistical analysis with the actual limited availability of field data in this particular study to make this analysis quantitatively meaningful. Although the transect lines we have chosen are probably the most sampled in the Canadian Beaufort Sea, this is still a limited number of data. We note that past studies, including recent studies using extensive mooring timeseries such as Forest et al. (2015) and Jackson et al. (2015), take a similar approach to our study and use inference to understand processes on the shelf. A numerical model sensitivity analysis of different factors affecting SPM distributions would, in our opinion, provide probably the best way forward to deduce statistical relationships. This would, however, constitute a separate study on its own and is beyond the scope of our study. Our result could be useful for evaluating such model and we have added this statement at the end of Conclusions section in the revised manuscript.

Finally, the discussion in paragraph 3.4.6. was the least convincing. Examples: 1) line 6, page 18: Fig. 12 does not show the cast-to-cast variability.
2) line 13, page 18: it is rather difficult to define the bottom layer thickness from the presented profiles.
3) lines 20-26: the authors may be able to see flow patterns of INLs, but the reader may as well see other patterns.
Again, a statistical analyses would (or not) remove any doubt about the proposed explanations of the different patterns of nepheloid layers.

REPLY: We have made significant modifications of this section. We no longer mention cast-to-cast variability. The text in lines 20-26 has been deleted. We have, however, kept the figure (originally Fig. 11, now Fig. 9) and a brief discussion of this figure, as we want to show one graph with individual cast (other cp data are shown only as contour plots) and illustrate the SPM concentrations on the shelf within a context of what is observed in offshore Canada Basin waters.

Figures: By consequence of my proposition, the figures 6, 7, 8, 9, 12 and maybe 11 would need to be modified or even removed and figure 10 remains the key figure.

Technical corrections

- Lines 1, 4, page 2: Mass units are generally given in g, i.e. Tg instead of Mt
REPLY: We have changed to Tg although we note that the source reference Macdonald et al. (1998) uses the units of Mt.

- Lines 5-6, page 2: If 50% are deposited in the delta and 40% on the shelf then the fraction across the shelf break is not poorly known, but should most likely be 10%
REPLY: The sentence has been rewritten as follows: "Macdonald et al (1998) recognize that sedimentation rates on the shelf are poorly known, but estimate that about 40% of the sediment input to the shelf is deposited while about 13 % is transported across the shelfbreak either in surface river plumes, near the bottom in nepheloid layers, or by ice rafting." The cited paper includes large ranges in these values.

- Line 30, page 2: ...part of the MALINA project...
REPLY: Added "the".

- Line 26, page 4: The blank value seems a bit high to me. Is this common for the used instrument?
REPLY: We have not been able to ascertain the typical blank values for this instrument. Note that our POC measurements were made on the same filters as were used for SPM. Thus, the blank filter preparation also followed the SPM protocol steps such as weighting, rinsing with milli-Q, etc. This may have contributed to higher blank values than what might be otherwise expected. Nevertheless, we filtered sufficient volumes of sample water such that the carbon signal on the filter was significantly higher than the blank values.

- Line 6, page 7: Instead of the questioned Matsuoka reference, I would suggest: McDonald et al., 1989, JGR and/or Carmack et al., 1989, JGR, which are the refs. mentioned in Matsuoka.
REPLY: Indeed, we did have the reference to Carmack et al. 1989 but unfortunately misspelled the citation reference in LaTex (hence the **?**). We have kept the reference of Matsuoka et al because it uses the same dataset as our study. This is now corrected.

- Line 8, page 8: ...Only at station 394....
REPLY: Corrected.

- Line 33, page 10: which transect is meant?
REPLY: Changed to "all the ship-based transects (Fig. 1)"

- Line 14, page 14: ...which corresponds to the Mackenzie....
REPLY: Corrected.

- Line 17, page 14: ...to the northerly and rather weak....
REPLY: Changed to: “to the northerly and, then later, weak winds”.

- Line 6, page 20: ...at a depth corresponding to an.....
REPLY: Corrected.

- Line 10, page 20: ...(Fig. 8d)....
REPLY: Corrected.

- Line 15, page 23: The reference Guay et al. is not cited in the manuscript - Line 25, page 24: Timmermans et al. should appear after Stroeve et al.
REPLY: Thank you. We removed Guay et al. and moved Timmermans et al.

RESPONSES to the review of the manuscript:

"Patterns of suspended particulate matter across the continental margin in the Canadian Beaufort Sea", Jens K. Ehn, Rick A. Reynolds, Dariusz Stramski, David Doxaran, Bruno Lansard, and Marcel Babin

We greatly appreciate the constructive comments from both reviewers. Here we provide our detailed point-by-point responses and any description of action taken in regards to the comments by Referee #2. The Referees' comments are shown in regular font; our responses follow each comment in blue font.

Response to Referee #2

I was very interested to read this manuscript, whose main goal is to develop a relationship between beam attenuation data collected by transmissometers and suspended particulate matter and particulate organic carbon. Much archived transmissometer data exist for this region so finding such relationships could give valuable historic information on suspended particles. This is a very complex region and others have struggled to find statistically significant relationships between these properties in such complex regions. In general, I think that the authors did a convincing job of showing that there are robust relationships.

It seemed like a secondary goal of this manuscript was to describe the physical forcing responsible for the high or low particulate concentrations. Unfortunately, this is where I think this manuscript fell apart. The interpretation of the physical data was vague and few solid conclusions could be made from the very long discussion. I got the sense that the authors had limited understanding of the physical oceanography of this region.

Perhaps a better approach would be to choose only one physical process that is related to suspended particles. I see the main storyline of the manuscript as a comparison between the attenuation and bottle data. Proof of concept of this relationship could be shown by focusing on only one process, such as the Mackenzie River plume. There is room here for a very thorough study of this process and much new information could be gained on by coming up with concrete conclusions related to one physical process.

REPLY: We would like to thank Referee #2 for insightful comments and suggestions for revisions that we feel have helped improve this manuscript. Specifically, we have followed the Referee's suggestion and used oxygen isotope data to determine freshwater sources. We have also reduced the discussion and focused on the summer season by removing data from the fall 2007.

Regarding choosing only one physical process: As stated by the Referee, the Mackenzie Shelf is a very complex region. We find that it is difficult to interpret SPM distributions in regards to a single physical process, as they respond to multiple and interrelated physical and biological processes occurring at different temporal and spatial scales. The goal is to simply to describe the SPM distributions, and attempt to interpret them within the context of all these processes.

I recommend that this manuscript undergoes major revision before it can be reconsidered for publication. Below are several other concerns and suggestions that I have:

- Page 1, line 6 – Several times throughout the manuscript, the authors state that the surface layer is a mixture of sea ice melt and river runoff. While this may be true, the composition of the surface layer hasn't been quantified so the source of the particles in the freshwater can't be determined. The authors could attempt a freshwater budget as was done by Yamamoto-Kawai et al. (2008, doi:10.1029/2006JC003858) or they can acknowledge that they don't know the source of the freshwater or the particles therein.
REPLY: Thank you for this advice. We have added an analysis of oxygen isotope data to help link the observed particle characteristics to freshwater sources. Furthermore, CDOM fluorescence in Fig. 3 also qualitatively indicates where ice meltwater (low CDOM) vs. river water (high CDOM) dominated the surface layer. We feel that these additions have helped achieve a better focus and improved the manuscript.

- The Introduction is in general quite confusing. I think that a more clear description of the region would greatly help readers not familiar with this area. In addition, a stronger literature review of previous SPM and POC work in this region, and the mechanisms that transport these particles, would set the stage nicely for focusing this manuscript.
REPLY: We have improved the introduction with a broader description of the study area. In particular, we have added the description of the submarine valleys and the effects of wind-forcing on shelf-basin exchange. We have added references for past SPM and POC studies in the region and other relevant studies within the world's ocean.

- Page 2, second paragraph – This paragraph is quite confusing and needs more focus
REPLY: The introduction has been substantially reworked. As a part of this, we expanded paragraph 2 as shown below (with the italic portion representing the original 2nd paragraph) to create on concise paragraph on SPM sources:

"The significance of sediment discharge to the region is underscored by the fact that this sediment load from the Mackenzie River surpasses the combined load of all other major rivers discharging into the Arctic Ocean. Additional sediment sources of minerogenic sediment to the shelf include coastal and bottom erosion, and other rivers, which have been estimated to provide ~9 Tg per year (Macdonald et al., 1998). This makes the Mackenzie Shelf the most turbid shelf sea in the Arctic Ocean. Biological production, *by both marine phytoplankton and sea ice associated algae towards the end of the ice-covered season, is a major authochthonous source of biogenous sediments in the Beaufort Sea during summer (Forest et al., 2007; Forest et al., 2010; Tremblay et al., 2008), although the ice and turbid seawater are thought to greatly limit primary production on the Mackenzie Shelf (Carmack and Macdonald, 2002). The particulate sinking flux therefore comprises highly variable fractions of allochthonous and autochthonous origins (Sallon et al., 2011), making particle characterization in the area a complex task. The vertical export of autochtonous organic material to the deep waters of Canada Basin is found to be surprisingly small, however (Honjo et al., 2010). As the organic material reaching the deep ocean layers is thousands of years old it must be transported there laterally from the shelf or slope reservoirs of highly refractory material (Honjo et al., 2010). This highlights the* *importance of understanding the distribution and lateral transport of particulate material from the shelf.*"

- Page 3, lines 14-15 – Why weren't lines 400 and 500 analyzed in this study?
REPLY: Unfortunately, there was not enough time during the MALINA expedition so that we needed to prioritize some stations and transects over others.

- Page 3, lines 25 -27 – What other depths were sampled in addition to the surface and SCM?
REPLY: There were large variations in other depths and their choice depended on the features seen on the CTD Rosette cast.

- Page 3, line 29 – What is an aliquot?
REPLY: Aliquot is a commonly used term defined as "a portion of a larger whole, especially a sample taken for chemical analysis or other treatment."

- Page 3, line 29 – What is considered a sufficient volume of water? Was this based on the time it took to filter or something else? What determines whether a duplicate or triplicate was sampled?
REPLY: Water from the Niskin bottles were in high demand on the cruise and used for analysis of many variables. We used as much water as was available and appropriate for our analysis. Seawater was passed through the filter to collect sufficient amount of particles but to avoid clogging of the filter. If the first sample filter required, for example, 4 L of water and only 6 L in total were available, then we did not collect a duplicate sample. We think this has been sufficiently described in the text, however, we added the information about "near-clogging" in the text.

- Page 4, lines 10 to 12 – Some other studies sampling SPM rinse the filters with ammonium bicarbonate or ammonium formate. Could the authors please explain why they didn't do this?
REPLY: We chose to rinse our filters with milli-Q to remove as much salt as possible but also avoid potential cell lysis. This is the most common procedure in SPM determination. Milli-Q water was readily available on the ship. We followed the method used in Babin et al. 2003 (as cited in the text), which essentially followed the JGOFS protocol described in Van der Linde, Protocol for determination of total suspended matter in oceans and coastal zones, Tech. Note I.98.182, Joint Res. Cent., Brussels, 1998. We also determined POC using the same sample filters.

- Page 5, line 8 – Please describe the interquartile range method, with a reference if applicable
REPLY: We have described it with the following sentence: "Time series of transmissometer data were also collected at selected depths and processed similarly to above, by taking the average of the interquartile range of the voltage values recorded over the periods when the rosette was stopped for water sampling during upcasts." There are no references for this method.

- Section 2.4 – Comparison of data between different transmissometers is notoriously difficult due to different calibration values and instrument drift. Is the use of dark voltage offset to allow for comparison of tranmissometer data between cruises? If so then could the authors please state the accuracy of this method, with references if applicable.
REPLY: The Vdark and Vref (representing particle-free seawater) are the calibration parameters

supplied with a C-Star and used to obtain beam transmittance and attenuation. The Vdark voltage offset is always done (but mostly directly within the Seabird CTD software). We have cited the Wetlabs C-Star user manual for how these are calculated, and the accuracy is stated by the manufacturer. It is worth noting that manufacturer calibrations are typically done at water temperatures of ~20 °C, but both Vdark and Vref values are sensitive to temperature. In brief, our processing of the C-Star raw voltage data is exactly the same as is typically done in the CTD software. However, as noted, there can be significant drift of the C-Star over time, and the ambient temperature can further affect the readings. To minimize these uncertainties, we have taken the approach to not to rely on the calibrated values (and here we note that the Vdark is of less importance compared to Vref in the relatively clear marine waters) but to determine them ourselves from the raw voltages measured at ambient temperature as described in the manuscript. For determining Vref we have used the clearest waters that we observed in the Arctic Ocean during the field campaigns, rather than pure water in the lab.

- Page 6, line 7 – What depth were the other sensors located at on the mooring?
REPLY: These sensors were all associated with the Aanderaa RCM11 and thus located at the same depth of 178 m.

- Section 2.5 – Why were data from only CA05 shown? This mooring is at the edge of the Cape Bathurst upwelling region, which is not particularly representative of the region. Several other moorings have been deployed along the Canadian Beaufort during the study period, 2004 to 2009. Why was only this mooring selected to represent the region?
REPLY: This mooring was located on our line 100, at the shelfbreak, so it is representative of our observations. These data also show well the change in the direction of the current at 178 m associated with upwelling.

- Page 6, line 28 – where is the proof that there were strong easterly winds in June 2009?
REPLY: Figure 8a (now Fig. 12a) shows that the wind direction during June was persistently from northeast (along the shelf).

- Section 3.1.1 – Please add some references to the different water mass definitions.
REPLY: We think that Carmack et al (1989) is a pertinent citation for water mass definitions for the study region. We have added the following sentence: “The water mass definitions that ensue follow Carmack et al (1989) and are consistent with descriptions in Lansard et al. (2012) and Matsuoka et al. (2012).” We removed these citations from the next sentence. We have also added a reference to Jackson et al. (2015).

- Page 7, lines 5-6 – Please see Jackson et al (2015, 10.1002/2015JC010812) for information on Pacific winter water in this region
REPLY: Thank you for suggesting this reference. We have included it.

- Page 7, lines 10 – 17 – The c_p values in this paragraph don’t appear to match those in Figure 2
REPLY: The range is correct. Note that the higher cp values are represented with white contour lines. The colour bar represents the full range.

- Page 7, line 18 – what does the 'strong chl-a fluorescence signal mean? Couldn't they be quantified by discrete chlorophyll samples?
REPLY: In principle, this could be done by 'calibrating' the fluorescence sensor with discrete chl-a measurements, but, as far as we know, this calibration has not been done on the data from the MALINA cruise. There are uncertainties associated with this calibration. We simply use the chl-a fluorescence (and CDOM fluorescence) in a qualitative sense to gain a better understanding of particle characteristics and patterns on the shelf. A 'strong chl-a fluorescence signal' simply means that the instruments detected higher fluorescence at these depths/locations than elsewhere, which is generally indicative of higher concentration of particles containing chl-a.

- Page 7, line 22 – What is the source of CDOM in Pacific Winter water? Perhaps more information can be added from Guegen et al., 2012 (doi:10.1016/j.dsr2.2011.05.004)
REPLY: The paper by Matsuoka et al (2012) describes the CDOM observations during MALINA. Therefore, we think that the addition of more information overlapping with the Matsuoka et al. study is not necessary in our manuscript. However, the CDOM source is likely associated with the decomposition of organic materials in the Bering and Chukchi Seas.

- Page 8, line 10 – There is no information about the location or methods used for barge sampling
REPLY: Barge sampling is described in Doxaran et al. (2012). We cited that study in that context. We have mentioned that barge stations were in the vicinity of the CCGS Amundsen, and also mentioned the transects to the Mackenzie River mouths.

- Page 8, lines 24 – 26 – Why is it not possible to measure PSD using the Coulter technique in low salinity, turbid waters?
REPLY: The Coulter Counter counts and sizes particles suspended in an electrolyte by aspirating sample through a small aperture and recording the change in the electrical impedance as particles pass through the aperture. In our case, the electrolyte is seawater. Reductions in salinity decrease the conductivity across the aperture and increases the noise associated with the measurement; below a certain threshold of salinity the uncertainties of the measurement become untenable.

Although turbid waters may pose a challenge because of the need for coincidence correction (accounting for multiple particles passing simultaneously through the aperture), this can generally be handled through appropriate dilution of the sample. In the present case, the statement "low salinity, turbid waters" is made simply because the waters near the river mouth were associated with both low salinity and high turbidity, not because of any limitation in the technique associated with turbidity per se.

- Page 8, line 32 – I disagree with this statement. The relationships shown in Figure 4b are not very convincing. Is the relationship statistically significant?
REPLY: We have deleted the first sentence. We did not test the statistical significance.

- Page 9, lines 8-10 – What is the difference between the MALINA and Amundsen data?
REPLY: No difference. It was used to specify the contrast between sampling from Amundsen

and barge during MALINA. For clarity we have changed "CCGS Amundsen" to "ship-based sampling".

- Page 9, lines 18 -20 – Of these three regression analyses, why is only ii) shown in Figure 5?
REPLY: We decided to clarify the results of regression analysis in the revised manuscript by moving details of this analysis to the Supplementary Materials, and keeping only the most essential regression fits actually utilized in the manuscript.

- Page 9, line 26 – do the authors mean 'nonlinear power function' instead of 'nonlinear least squares regression'?
REPLY: Firstly, the description containing this sentence has been deleted and moved to the Supplementary Materials. Secondly, in the Supplementary Materials, we have now written: "Therefore, we selected the SPM vs. $c_p(660)$ relationship obtained from the power function fit using nonlinear least squares regression to ordinary (non-transformed) variables as the algorithm for estimating SPM in [g m^{-3}] from $c_p(660)$ in [m^{-1}] in the rest of this study".

- Page 12, lines 20 – 26 – Figure 8 is very unclear and possibly incorrect. I can't see the statements in this paragraph supported in Figure 8
REPLY: In our opinion, progressive vector plots are the best way to display the overall wind and current regimes. We have improved the clarity of the figure and we see no problems that could make it incorrect. We have marked the timing of the expeditions on all plots, removed the fall 2007 period, and removed the observations from 54 m depth in an effort to clarify the figure.

- Page 12, line 28 – I can't see the wind speeds in Figure 8a
REPLY: The colour of the progressive vector plot indicates wind speed.

- Page 12, lines 31-35 – Don't these lines contradict lines 11-13 on page 12?
REPLY: Yes, indeed. We did not mention the one week period of southeasterly winds during the last week of July. We have added the sentence "Winds turned to southwesterly for the last week of July with wind speed > 8 m s^{-1}".

- Section 3.3.3. This section need much more work. How was cross-shelf defined? What depths were influenced by cross shelf currents? How do we know that the currents observed at CA05 were representative of the rest of the region? How was a cross-shelf episode defined? I'm not entirely sure how this section is giving evidence of upwelling and relaxation
REPLY: As indicated cross-shelf current was defined by the direction of 300 degrees as indicated by the change in direction in the progressive vector current plot (original Fig. 8b, now Fig. 12b). We have not tried to expand this analysis of currents to cover the full Mackenzie Shelf region. This is beyond the scope of our study. More information on modelled currents can be found, for example, in Mol et al. (2018) which is cited. The increase in salinity and temperature during upwelling episodes are an indication of upwelling of deeper waters that are more salty and warm. The upwelling shelfbreak flow is also linked with seaward Ekman transport of surface waters during which the plume extends further north and northwest. This reverses during downwelling inducing winds or relaxation of upwelling. We show that the SPM patterns on the shelf reflect this circulation.

- Section 3.3.4 – I don't see the point of this section. What new information does it tell us about SPM and POC in the Canadian Beaufort Sea?
REPLY: Section 3.3.4 describes the geostrophic currents which were used to detect the shelf break jet and the overall circulation on the shelf. This information clearly has bearing on SPM distributions on the shelf. Beam attenuation values were noticeably elevated at the shelf break jet, so the jet plays a role in resuspending particles and/or keeping particles in suspension. The occurrence of the shelf break jet is an indication for downwelling flow (e.g. Dmitrenko et al. 2016; Forest et al. 2015). We argue that this plays a role in SPM patterns on the shelf.

- Page 13, line 29 – Could the authors please be more clear with where the current intensification is observed? I refer the authors to Forest et al (2015, http://dx.doi.org/10.1016/j.csr.2015.03.009) for discussion of other strong shelfbreak currents in the region
REPLY: We have rewritten this section and it is now incorporated in section 3.1 (page 8). We have included a reference to Forest et al 2015. We have been more specific by saying "along the Makenzie Shelf shelfbreak" instead of "at this location".

- Page 14, lines 10- 11 – What causes this clear water extension onto the shelf?
REPLY: The particles originate from the river and shelf bottom. Therefore, the absence of particles in the clear water layer reflects the water column structure and dynamics, with the river plume in a stratified surface layer from which particle settling is limited, and bottom resuspension reaching only a certain level. This leaves a clear layer in between. We have described this in the text on page 12 (4th paragraph).

- Page 14, lines 24-25 – Is there proof of downwelling return flow and after upwelling?
REPLY: Yes, the mooring record, its link to wind speed and direction, the geostrophic current sections, and SPM patterns are all evidence for Ekman upwelling/downwelling.

- Section 4 – I am unclear exactly how the physical observations described in section 3 lead to the listed conclusions in section 4. Much more work needs to be done to understand the physical processes before they can be related to the particle concentrations
REPLY: We feel that the addition to the revised manuscript of freshwater source analysis has strengthened this link. We have also removed data from the fall 2007, rearranged and tried to better focus the text in order to address this issue.

- Figure 1 – Please make the CA05 mark larger and easier to see o It is difficult to distinguish between the different colored stars
REPLY: We added a green arrow pointing to the CA05 mark. We have furthermore added a list of station locations in the Supplementary Materials.

- Figure 2 – Why is the very freshest water on the western shelf away from the Mackenzie River? It doesn't appear that this very fresh water is correlated with the highest attenuation o It would help the reader understand the text if the stations could be marked on these figures o What does the grey area mean?
REPLY: The grey area is below the bottom so no data at the depth exists. The wind direction in 2009 was such that the Mackenzie River plume was pushed eastward. This was also linked to upwelling, as can be seen from the current data. Attenuation values were elevated in the plume,

however, seasonal timing play a role here as, for example, the SPM values in July 2004 (Fig. 7g) were an order of magnitude higher than in August 2009 (Fig. 7h). In August 2009, the highest cp(660) on the shelf are indeed not in the freshest part of the plume, but towards the east. Interestingly, this is also linked to higher salinity. Thus, we draw the conclusion that the wind, the upwelling and tides (which are not discussed in detail) caused resuspension of sediment in the shallow eastern portion of the shelf. Note also that prior to MALINA, during the first part of July, there was a period of northerly winds that pushed the river plume along the shore towards east. Some of the suspended particles may have been remnants from the earlier eastward-moving alongshore plume.

- Figure 3 – Why are the error bars backwards?
REPLY: Figure 3 does not include error bars. If the reviewer is referring to the color bar scale, we have reversed the direction (lowest to highest values going from left to right) in the revised manuscript.

- Figure 4 – It would help the reader interpret this if boundaries were drawn around the 3 different defined areas o Figure 4b – I don't see very strong, statistically significant relationships here. Also, is the salinity from the same depth that the water was sampled from?
REPLY: We have redone this figure to show the POC/SPM boundaries of 0.06 and 0.25 between mixed and organic-dominated particle assemblages. 4b: We agree that there is not a strong statistical relationship here. The point of the figure is to show the range of PSDs. However, there is a strong relationship between the river runoff fraction and POC/SPM (as shown in new Fig. 5b).

- Figure 6 – It is difficult to see the writing of the different cruises
o The data look smoothed. Can the authors please state how they smoothed the data?
REPLY: We have increased the size of the figure. The data has not been smoothed by us. What is plotted is the data downloaded from Environment Canada (http://wateroffice.ec.gc.ca/) and the Canadian Ice Service.

- Figure 8 – I really struggled with this figure. It is difficult to interpret, has very small writing, and has a huge amount of information.
o The wind and current data in particular were difficult to distinguish. It was near impossible to see upwelling or downwelling as this figure was laid out
o I think that the depths in the temperature and salinity plots were mislabeled – the shallower water shouldn't be saltier
o There should be some explanation as to why such salty water was observed in figure 8d. Water of this salinity would have to be upwelled from several hundred meters depth, and a significant upwelling event would need to be evident in the wind data.
o I don't understand what the different colours mean in 8c
REPLY: We are sorry about the figure presentation and agree it is a complex figure with lots of information. In the revised manuscript, we have inserted a larger figure which is intended as a full page width figure. When the paper is prepared in final form for publication we will make additional improvements, if needed, to ensure that all details are clear. We have also simplified this figure by removing the extra depth of 57 m and the turbidity, to just focus on the 178 m data..

- It was not mislabeled. However, the plots were on different scales. This is no longer an issue.
- The timing of upwelling inducing winds (a) and upwelling events (b-d) are consistent. Same is true for downwelling events.
- Colours are current direction which is more easily seen in (b).

- Figure 9 – Please mark the mooring location on line 100 (CA05)

REPLY: Done

o I couldn't distinguish between the different contour lines

REPLY: Figure is now larger which hopefully helps.

o Please include the station locations

REPLY: We have not included station locations, however, the small black dots indicate the profiles taken at the station locations.

o The current values don't make sense to me. General definitions in oceanography are that northward and eastward currents are positive and southward and westward currents are negative. Having different definitions makes this figure very confusing

REPLY: Geostrophic current calculations can only give speeds that are perpendicular to the transect line. We could divide this speed up in U and V components, however, since our transect lines are nearly perpendicular to the shelf break, the calculated geostrophic currents represent along-shelf current magnitude. Note that this is consistent with what has been done in other studies (e.g., Forest et al., 2015).

Latexdiff
produced errors which I
could not solve. Therefore, I used
microsoft office to perform a comparison
between the originally submitted LaTeX tex
file and the revised manuscript tex file.

Deletions are in red with strikethrough
Additions in blue
Moved text in blue underlined and
red doublestriked text

```
%% Copernicus Publications Manuscript Preparation
Submissions
```
~~%% ---------------------------------~~
```
%% ---------------------------------
%% This template should be used for copernicus.c
%% The class file and some style files are bundl
Latex Package, which can be downloaded from the d
webpages.
%% For further assistance please contact Copernic
production@copernicus.org
%%
https://publications.copernicus.org/for_authors/manuscript_preparation.ht
ml


%% Please use the following documentclass and journal abbreviations for
discussion papers and final revised papers.

%% 2-column papers and discussion papers
\documentclass[journal abbreviation, manuscript]{copernicus}
```

~~%% Journal abbreviations (please use the same for discussion papers and final revised papers)~~

~~% Advances in Geosciences (adgeo)~~
~~% Advances in Radio Science (ars)~~
~~% Advances in Science and Research (asr)~~
~~% Advances in Statistical Climatology, Meteorology and Oceanography (ascmo)~~
~~% Annales Geophysicae (angeo)~~
~~% Archives Animal Breeding (aab)~~
~~% ASTRA Proceedings (ap)~~
~~% Atmospheric Chemistry and Physics (acp)~~
~~% Atmospheric Measurement Techniques (amt)~~
~~% Biogeosciences (bg)~~
~~% Climate of the Past (cp)~~
~~% Drinking Water Engineering and Science (dwes)~~
~~% Earth Surface Dynamics (esurf)~~
~~% Earth System Dynamics (esd)~~
~~% Earth System Science Data (essd)~~
~~% E&G Quaternary Science Journal (egqsj)~~
~~% Fossil Record (fr)~~
~~% Geographica Helvetica (gh)~~
~~% Geoscience Communication (gc)~~
~~% Geoscientific Instrumentation, Methods and Data Systems (gi)~~
~~% Geoscientific Model Development (gmd)~~
~~% History of Geo- and Space Sciences (hgss)~~
~~% Hydrology and Earth System Sciences (hess)~~
~~% Journal of Micropalaeontology (jm)~~
~~% Journal of Sensors and Sensor Systems (jsss)~~
~~% Mechanical Sciences (ms)~~

```
% Natural Hazards and Earth System Sciences (nhess)
% Nonlinear Processes in Geophysics (npg)
% Ocean Science (os)
% Primate Biology (pb)
% Proceedings of the International Association of Hydrological Sciences
(piahs)
% Scientific Drilling (sd)
% SOIL (soil)
% Solid Earth (se)
% The Cryosphere (tc)
% Web Ecology (we)
% Wind Energy Science (wes)


%% \usepackage commands included in the copernicus.cls:
%\usepackage[german, english]{babel}
%\usepackage{tabularx}
%\usepackage{cancel}
%\usepackage{multirow}
%\usepackage{supertabular}
%\usepackage{algorithmic}
%\usepackage{algorithm}
%\usepackage{amsthm}
%\usepackage{float}
%\usepackage{subfig}
%\usepackage{rotating}


\begin{document}

\title{Patterns of suspended particulate matter across the continental
margin in the Canadian Beaufort Sea}

 during summer}

% \Author[affil]{given_name}{surname}
\Author[1]{Jens K.}{Ehn}
\Author[2]{Rick A.}{Reynolds}
\Author[2]{Dariusz}{Stramski}
\Author[3]{David}{Doxaran}
\Author[4]{Bruno}{Lansard}
\Author[5]{Marcel}{Babin}

\affil[1]{Centre for Earth Observation Science, University of Manitoba,
Winnipeg, Manitoba, Canada.}
\affil[2]{Marine Physical Laboratory, Scripps Institution of
Oceanography, University of California San Diego, La Jolla, California,
U.S.A.}
\affil[3]{Sorbonne Universit√©, CNRS, Laboratoire d,ÄôOc√©anographie de
Villefanche, Villefranche-sur-mer 06230, France.}
\affil[4\affil[4]{Laboratoire des Sciences du Climat et de
l,ÄôEnvironnement, LSCE/IPSL, CEA-CNRS-UVSQ-Universit√© Paris Saclay,
91198 Gif-sur-Yvette, France}
```

\affil[5]{Joint International ULaval-CNRS Laboratory Takuvik, Qu√©bec-Oc√©an, D√©partement de Biologie, Universit√© Laval, Qu√©bec, Qu√©bec, Canada.}

%% The [] brackets identify the author with the corresponding affiliation. 1, 2, 3, etc. should be inserted.

\runningtitle{SPM in Canadian Beaufort Sea}

\runningauthor{Ehn et al.}

\correspondence{Jens K. Ehn (jens.ehn@umanitoba.ca)}

\received{}
\pubdiscuss{} %% only important for two-stage journals
\revised{}
\accepted{}
\published{}

%% These dates will be inserted by Copernicus Publications during the typesetting process.

\firstpage{1}

\maketitle

\begin{abstract}
The particulate beam attenuation coefficient at 660 nm, $c_\mathrm{p}(660)$, was measured in conjunction with properties of suspended particle assemblages in August 2009 within the Canadian Beaufort Sea continental margin, a region heavily influenced by freshwater and sediment discharge from the Mackenzie River~~.~~, but also by sea ice melt. The mass concentration of suspended particulate matter~~ mass concentration~~ (SPM) ranged from 0.04 to 140 g m^{-3}, its composition varied from mineral to organic-dominated, and the median particle diameter ~~ranged ~~determined over the range 0.7--120 μm varied from 0.78 to 9.45 μm, with the fraction of particles < 1 μm ~~highest ~~in surface ~~layers~~waters reflecting the degree influenced by river water~~ or ice melt. A~~. Despite this range in particle characteristics, a strong relationship between SPM and $c_\mathrm{p}(660)$ was ~~developed~~found, and used to determine SPM distributions across the shelf based on measurements of $c_\mathrm{p}(660)$ taken during summer seasons of 2004, 2008, and 2009~~, as well as fall 2007.~~. SPM spatial patterns on the ~~shelf are explained by an interplay between wind forcing, river discharge, and sea ice coverage resulting in three ~~stratified shelf reflected the vertically sheared two-layer estuarine circulation ~~modes:~~and SPM sources (i.e., fluvial inputs, bottom resuspension, and biological productivity).

Along-shelf winds generated lateral Ekman flows, isopycnal movements, and upwelling or downwelling at the shelfbreak~~ upwelling, relaxation of upwelling, and vertical mixing. Offshore ice melt affected the~~. Cross-shelf transects measured during three summers illustrate how sea ice meltwater affects river plume extent, while the presence of meltwater on the shelf was associated with enhanced near-bottom SPM during ~~upwelling~~ return flow~~.~~ of upwelled Pacific-origin water.   SPM decreased sharply past the shelfbreak with further transport of particulate matter occurring near the bottom and in interleaving nepheloid layers. ~~The deepest nepheloid layer was observed near 2600 m depth, immediately below the transition to the Canada Basin Bottom Water mass. ~~These findings expand our knowledge of particle distributions in the Beaufort Sea controlled by river discharge, sea ice, and wind, each of which is sensitive to weather and climate variations.
\end{abstract}

% \copyrightstatement{TEXT}

\introduction %% \introduction[modified heading if necessary]
The ~~Canadian~~Mackenzie Shelf in the southeastern Beaufort Sea (Arctic Ocean) is subject to great seasonal and interannual variability in its sea ice coverage \citep{Galley_etal_2008, Yang_2009, Stroeve_etal_2014}, freshwater input \citep{McClelland_etal_2012}, and atmospheric forcing \citep{Yang_2009, Asplin_etal_2012, Moore_2012, Kirillov_etal_2016}, all of which strongly influence the water circulation~~. In particular, the region includes the Canadian Beaufort Shelf, which is the most turbid of all shelf seas in the Arctic Ocean. High attenuation of solar radiation by both the ice and turbid seawater greatly limit primary productivity on the shelf \citep{Carmack_Macdonald_2002}. The Canadian Beaufort Shelf~~ and particle dynamics. The shelf is about 120 km wide, 500 km long, < 80 m deep, and is estimated to receive on average about 330 km^3 per year of freshwater from the Mackenzie River with a sediment load of 130 ~~Mt~~Tg per year \citep{Macdonald_etal_1998, OBrien_etal_2006}.
The large freshwater load, both from river runoff and sea ice melt, results in the Mackenzie Shelf displaying typical stratified estuarine circulation characteristics \citep{Carmack_Macdonald_2002}.
The Mackenzie Shelf is bordered to the east by Amundsen Gulf, to the west by the Mackenzie Trough, and is intersected at $\sim$134° W by Kugmallit Valley. These are all shown to be locations of intensified shelf-basin exchange driven by winds and modified by sea ice interactions \citep[e.g.,][]{Dmitrenko_etal_2016, Forest_etal_2015, OBrien_etal_2011, Williams_Carmack_2008}.
Easterly along-shelf winds generate offshore Ekman transport of surface waters and upwelling of nutrient-rich Pacific-origin water onto the shelf, whereas westerly winds create downwelling flow and enhance offshore transport of sediment in the bottom boundary layer. Much of the sediment transport occurs during winter and is associated with storms, eddy transport, and sea ice brine convection \citep{Forest_etal_2015, OBrien_etal_2011}.

The significance of sediment discharge to the region is underscored by the fact that this sediment load from the Mackenzie River surpasses the combined load of all other major rivers discharging into the Arctic

Ocean. Additional sediment sources of minerogenic sediment to the shelf include coastal and bottom erosion, and other rivers, which have been estimated to provide $\sim$9 ~~Mt~~Tg per year \citep{Macdonald_etal_1998}. ~~The bulk of the sediment carried by~~ This makes the Mackenzie ~~River is deposited~~Shelf the most turbid shelf sea in the ~~delta ($\sim$50 \% of input) and on the shelf ($\sim$40 \%); however, a poorly known fraction of particles is transported across the shelfbreak carried either in surface river plumes, near the bottom in nepheloid layers, or by ice rafting \citep{Macdonald_etal_1998}. Resuspension of sediments settled on the shelf bottom are thought to play a significant role in the cross-shelf transport in the nepheloid layers \citep{OBrien_etal_2011}.~~

~~Additionally,~~Arctic Ocean. Biological production, by both marine phytoplankton ~~production, including the contribution by sea~~-and sea ice associated algae towards the end of the ice-covered season, is a major authochthonous source of biogenous ~~particles~~sediments in the Beaufort Sea during summer \citep{Forest_etal_2007, Forest_etal_2010, Tremblay_etal_2008~~}.~~ }, although the ice and turbid seawater are thought to greatly limit primary production on the Mackenzie Shelf \citep{Carmack_Macdonald_2002}.
The particulate sinking flux therefore comprises highly variable fractions of allochthonous and autochthonous origins \citep{Sallon_etal_2011}, making particle characterization in the area a complex task. The vertical export of autochtonous organic material to the deep waters of Canada Basin is found to be surprisingly small, however \citep{Honjo_etal_2010}. As the organic material reaching the deep ocean layers is thousands of years old it must be transported there laterally from the shelf or slope reservoirs of highly refractory material \citep{Honjo_etal_2010}. This highlights the importance of understanding the distribution and lateral transport of particulate material from the shelf.

The mechanisms and pathways of cross-shelf and slope particle transport in the ~~Canadian~~ Beaufort Sea continental margin remain poorly understood \citep{OBrien_etal_2011}. This is largely because of a lack of data of sufficient resolution; biogeochemically important constituents in such a large and dynamic system are difficult to characterize with traditional methods that rely on discrete water sampling. To infer particle transport pathways, a description of the distribution and variability of particle concentrations associated with the factors controlling the water circulation is required. Ocean ~~color~~colour remote sensing of suspended particles provides a much better spatial coverage, but is limited to surface waters~~.~~ during cloud free conditons during certain periods of the seasonal cycle. In situ optical techniques, most commonly involving a measurement of beam attenuation coefficient, allow a significant increase in observational time and space scales.
The beam attenuation at light wavelength of 660 nm has been typically used in these relationships. Because beam attenuation is sensitive not only to the concentration of particles but also their size and composition, numerous relationships have been developed to relate the particulate beam attenuation coefficient, $c_\mathrm{p}(\lambda)$ (where λ is light wavelength in vacuo) to the dry mass concentration of suspended particulate matter (SPM) and particulate organic carbon (POC) \citep[e.g.,][]{Bishop_1986, Bishop_1999, Bunt_etal_1999,

Gardner_etal_2006, Stramski_etal_2008, Jackson_etal_2010, Hill_etal_2011}.
The proportion of organic to inorganic material is important because mineral particles typically have higher refractive index compared to organic particles, and thus generally produce higher scattering per unit mass concentration \citep[e.g.,][]{The beam attenuation at light wavelength of 660 nm has been typically used in these relationships.

Babin etal 2003b, Wozniak etal 2010}. Beam attenuation is also affected by variable absorption. In particular, at 660 nm the absorption by chlorophyll pigments may cause important distinctions between organic and inorganic material \citep{Doxaran etal 2012, Belanger etal 2013}. Particle size is of importance because the scattering cross-section of individual particles typically increases as particle size increases \citep{Morel Bricaud 1986, Stramski Kiefer 1991}. However, particle concentration often decreases significantly with an increase in particle size so that relatively small particles can have higher contribution to bulk scattering per unit mass concentration of particles than larger particles \citep{Babin etal 2003b, Reynolds etal 2010, Hill etal 2011}.

Because of various origins and variable composition of particle assemblages in the southeastern Beaufort Sea, the feasibility of inferring SPM and POC from beam attenuation has been questioned for this region \citep{Jackson_etal_2010}.
Nevertheless, in this study we use a comprehensive set of field data collected as part of the MALINA project in summer 2009 in waters with diverse composition of particulate matter characterized by variation in the ratio of POC/SPM to determine statistical relationships between the particulate beam attenuation coefficient at 660 nm, $c_\mathrm{p}(660)$, and SPM and POC. These relationships are then applied to infer the particle concentration fields from the measurements of beam attenuation taken during cruises to the Canadian Beaufort Sea associated with the MALINA project as well as four other projects. Although we recognize the possibility$c_\mathrm{p}(660)$. The distribution of interannualSPM and seasonalPOC on the Mackenzie Shelf displayed complex spatial variability that could not be explained in particle characteristics, our analysis aims at deriving information on how particle distributions along transects crossing the Canadian Beaufort Sea continental margin into the Canada Basin during the open water season are linkedterms of a single parameter. The variability was found to be related to forcing and oceanographic conditions, and affected by (wind forcing, river dischargespeed and direction, sea ice coverage.

, and freshwater content and source), both present and foregone, which control the circulation and water mass properties on the shelf. To gain a better contextual understanding of the effect of the forcing and oceanographic conditions on particle concentration fields, we compare and contrast the MALINA observations to two other expeditions to the southeastern Beaufort Sea during the open water season that also included beam attenuation measurements.

\section{Materials and Methods}
\subsection{MALINA sampling overview}

The MALINA expedition was conducted from 31 July to 24 August 2009 in the southeastern Beaufort Sea on the research icebreaker \textit{CCGS Amundsen}. A total of 167 CTD/Rosette casts were carried out during the expedition with water sampling conducted at 28 station locations (Fig. ~~1).~~\ref{fig:MAP}). The locations, sampling times and bottom depths are provided in Table S1 in the Supplementary Materials. A small barge was launched to conduct coincident surface water sampling away from the ship‚Äôs influence on 26 of these stations. In addition, the barge visited 12 additional stations in coastal waters too shallow for the ship \citep[Fig. ~~1;][][~~\ref{fig:MAP};][]{Doxaran_etal_2012}. The CTD/Rosette onboard the icebreaker was equipped with 24 12-liter Niskin bottles for water collection and various in situ instruments including an SBE-911plus CTD (Sea-bird Electronics, Inc.), a C-Star 25-cm beam transmissometer (Wetlabs, Inc.) for measuring particulate beam attenuation coefficient at 660 nm, $c_\mathrm{p}(660)$ in units of m^{-1}, and a Wetstar fluorometer (Wetlabs, Inc.) for measuring fluorescence of chlorophyll-\textit{a} (chl-\textit{a}).

~~In this study, the discussion is centered on the analysis and cross section plots for transect lines 100, 200, 300 and 600 only. Line 100 crossed the Amundsen Gulf near its entrance from north of Cape Bathurst towards the southwestern point of Banks Island. Lines 200 and 300 were south-to-north transects located approximately along 130° W and 134° W, respectively, with the latter associated with the Kugmallit Valley. The line 600 followed the Mackenzie Trough and provided the western border to the Mackenzie shelf. The Mackenzie River delta is a maze of channels; however, the main discharge channel exits at Mackenzie Bay near the end of line 600, while the second largest channel exits at Kugmallit Bay near line 300. Transect lines 100, 300, and 600 have been also repeatedly measured during other field campaigns \citep[e.g.,][]{Carmack_etal_1989, Tremblay_etal_2011}.~~

\subsection{Determinations of SPM and POC}
~~Water samples for SPM and POC determinations were collected at 28 CTD/Rosette stations and 38 barge stations (12 stations along two transects towards the Mackenzie River mouths and the remaining located in the vicinity of the ship stations (Fig. 1); see also \citet{Doxaran_etal_2012}).~~ Niskin bottles were triggered during CTD/Rosette upcasts to collect water samples at 3 to 4 depths, which always included the near-surface water (1.5--3 m depth range) and subsurface chlorophyll-\textit{a} maximum (SCM) if present. To ensure representative sampling of entire particle assemblages within Niskin bottles (including particles settled below the level of the spigot), the full content of the 12-liter Niskin bottles was drained directly into 20-liter HDPE carboys (Nalgene) by opening the bottom lid \citep{Knap_etal_1996}. Aliquots were then sampled from the carboys after mixing. If sufficient volume of water was available, filtration for SPM and POC determinations was made in triplicate for each examined depth. However, this was not always possible in clear waters with low particle concentrations, in which case either duplicates or single samples were prepared. Water samples for SPM and POC on the barge were collected by directly submerging a 20-liter HDPE carboy below the ~~seawater~~sea surface \citep{Doxaran_etal_2012}. \citet{Doxaran_etal_2012} reports on coefficient of variations for SPM and POC for these surface samples

measured in triplicate. Additional near-surface water samples were occasionally collected by lowering a bucket from the side of the ship.

Water samples for SPM and POC were filtered through 25 mm diameter Whatman GF/F filters under low vacuum ~~($~~($\leq$ 5 psi). Prior to the cruise the filters for both SPM and POC determinations had been rinsed with Milli-Q water, combusted at 450 $^{\circ}$C for 1.5 hours to remove organic material, and weighed using a Mettler-Toledo MT5 balance ($\pm$0.001 mg precision) to obtain the blank measurement of the filter mass. Filters were stored individually in Petri dishes until the time of sample filtration. The volume of filtered seawater was adjusted to optimize particle load on the filter~~.~~, but not to cause filters to clog. This volume ranged from 0.2 L for very turbid samples collected near the Mackenzie River mouth (station 697) to 5.8 L at station 780. Immediately following filtration, filters were rinsed with about 50 mL of Milli-Q water to remove salts, transferred back to the Petri slides, and dried for 6-12 h at 55 $^{\circ}$C. The dried filters were stored at $-$80 $^{\circ}$C until processing. After the cruise, filters were again dried at 55 $^{\circ}$C in the laboratory for about 24 h before measuring their dry weight using the same Mettler-Toledo MT5 balance. The SPM (in units of g m^{-3}) was determined by subtracting the blank filter mass from the sample filter mass and dividing by the volume of water filtered. The relative humidity of the room was about or below 40 \% during weighing of filters to minimize the effect of uptake of moisture by the filters during the measurements. The protocol used for SPM determinations is consistent with standard methodology \citep[e.g.,][]{ Babin_etal_2003a}.

SPM and POC were determined on the same GF/F filters. After the weighing for SPM, POC content was determined with an Organic Elemental ~~Analyzer~~Analyser (PerkinElmer 2400 Series II CHNS/O) with a standard high-temperature combustion method as described in \citet{Doxaran_etal_2012}. Prior to insertion of samples into the analyzer, the filters were acidified with 200-350 μL of 2N HCl~~ 2N~~ to remove inorganic carbon and then dried at 60 $^{\circ}$C. Filters were compacted into small ($\sim$5 mm diameter) rounded pellets within pre-combusted aluminum foil. Blank filters for POC determinations were treated and measured in the same way as sample filters. The combustion temperature was kept at 925 $^\circ$C. The final POC values (in units of g m^{-3}) were calculated by dividing the mass of organic carbon measured (in units of μg) on the sample filter (corrected for blank filter) by the filtered volume. In these calculations, the correction for blank filters was made using the average mass concentration of organic carbon determined on 9 blank filters, which was determined to be 21.2 $\pm$ 8.1 μg (corresponding to a range of $\sim$2 to 50 \% of measured signal for the sample filters~~; standard deviation was 8.1 μg).~~).

\subsection{Particle size distributions}
The particle size distribution (PSD) of 54 discrete seawater samples collected with the CTD/Rosette or from the barge were measured using a Beckman-Coulter Multisizer III ~~analyzer~~analyser following the method described by \citet{Reynolds_etal_2016}. In 40 of these samples, data were collected using both the 30 μm and 200 μm aperture sizes and merged into a single PSD ranging from 0.7 μm to 120 μm. Seawater

filtered through a 0.2 μm filter was used as the diluent and blank, and multiple replicate measurements were acquired for each sample. Each aperture was calibrated using microsphere standards following recommendations by the manufacturer. The average number of particles per unit volume within each size class, $N(D)$ (in units of m^{-3}), where D is the midpoint diameter of the volume-equivalent sphere in each size class, was obtained after subtracting the counts for the blank. The particle volume distribution, $V(D)$ (dimensionless), was then calculated from $N(D)$ by assuming spherical particles.

\subsection{Beam attenuation measurements}
C-Star transmissometer data were recorded at 24 Hz as raw voltages and merged with the depth recording from the CTD/Rosette. Downcasts were processed to 1-m vertical bins centered at integers by averaging the interquartile range of the voltages within bins. This method effectively removed spikes and noise from the data, if present. Time series of transmissometer data were also collected at selected depths and processed ~~using~~similarly to above, by taking the average of the interquartile range ~~method for~~of the voltage values recorded over the periods when the rosette was stopped ~~during upcasts~~ for water sampling ~~with Niskin bottles~~during upcasts. These data were used for correlational analysis with SPM and POC data from discrete Niskin bottle water samples. The particulate beam attenuation coefficient at 660 nm, $c_\mathrm{p}(660)$ (in units of m^{-1}), was then calculated from the binned voltage signal, V_signal, as
\begin{equation}
c_\mathrm{p}(660) = -\ln \left(\frac{V_\mathrm{signal} - V_\mathrm{dark}}{V_\mathrm{ref} - V_\mathrm{dark}} \right) / x
\end{equation}

where x is the pathlength of 0.25 m, V_dark is the dark voltage offset, and V_ref is the reference voltage associated with particle free pure seawater (cf. C-Star User,Äôs Guide, Wetlabs, Inc.). ~~For MALINA, V_dark was found to be 0.0517 V when measured immediately after a deep cast when the temperature of the instrument was equilibrated to seawater temperature.~~
For MALINA, V_ref was taken as the highest V_signal reading observed during the expedition, i.e., it was determined to be 4.7362 V (lower than the factory supplied value of 4.8340 V) observed with the same instrument during the Geotraces cruise that followed immediately the MALINA cruise (cast 0903_26 on 4 September at depths between 1900 and 2500 m where water temperature and salinity averaged $-$0.40 $^{\circ}$C and 34.94 PSU, respectively). This V_ref was only marginally higher than maximum values observed during the MALINA expedition. The above method also assumes a negligible contribution by CDOM to c_p at 660 nm \citep{Bricaud_etal_1981}, which is a reasonable assumption based on data shown in \citet{Matsuoka_etal_2012}.

V_dark was found to be 0.0517 V when measured immediately after a deep cast when the temperature of the instrument was equilibrated to seawater temperature. The factory supplied value was 0.061 V. However, discrepancies in V_dark are of little significance compared to V_ref. For example, for relatively turbid conditions with V_signal as low as 3.7 V (representing a $c_\mathrm{p}(660)$

of 1 m^{-1}), the change from 0.0517 to 0.061, reduce the calculated $c_\mathrm{p}(660)$ by only 0.2 \%.

In this study we also use the C-Star transmissometer data obtained during CASES (2004~~), ArcticNet (2007~~) and IPY-CFL (2008) expeditions on the \textit{CCGS Amundsen} \citep{Ingram_etal_2008, Barber_etal_2010~~).~~} to compare and contrast to the MALINA observations. The data were processed in the same way as the MALINA 2009 downcast data. One exception was that the factory supplied V_dark values were used exclusively as they had not been determined onboard the vessels. The V_dark values were 0.0570 V~~, 0.0574 V,~~ and 0.0586 V for the CASES~~, ArcticNet,~~ and IPY-CFL expeditions, respectively. The highest V_signal readings were 4.6783 V~~, 4.6498 V,~~ and 4.7902 V, respectively.

Four deep CTD casts were additionally collected in the Canada Basin during the Joint Ocean Ice Study (JOIS) on 21-23 September 2009 and the data were obtained from the Beaufort Gyre Exploration Program website (http://www.whoi.edu/beaufortgyre). These transmissometer data were processed as described above with a V_dark value of 0.0633 V (factory calibration) and V_ref value of 4.9408 V (maximum recorded value at station CB-21 on 9 October 2009).

\subsection{Determination of surface water mass distributions}
During the MALINA expedition, water samples were collected at 51 stations on the Mackenzie Shelf either by the CTD/Rosette or from the barge. Oxygen isotope ratio ($\delta^{18}O$) were analysed at the Light Stable Isotope Geochemistry Laboratory (GEOTOP-Universit√© du Qu√©bec √† Montr√©al) using a triple collector IRMS in dual inlet mode with a precision of $\pm$0.05 \permil. Total alkalinity (\textit{TA}) was measured by open-cell potentiometric titration (TitraLab 865, Radiometer¬Æ) with a combined pH electrode (pHC2001, Red Rod\textregistered) and diluted HCl (0.03 M) as a titrant. Oxygen isotopes and \textit{TA} collected during CASES 2004 are described, and partially published, in \citet{Lansard_etal_2012}. We use salinity (S), $\delta^{18}O$ and \textit{TA} data to estimate the fractional composition of sea ice meltwater (f_{SIM}) and meteoric water (f_{MW}) in the surface layer on the Mackenzie Shelf, following the protocol described in \citet{Lansard_etal_2012}. The calculations follow \citet{Yamamoto-Kawai_etal_2008} and \citet{Lansard_etal_2012} with the sea ice melt (SIM) end-members 4.7 PSU, -2.5 $\permil$ and 415 μmol kg^{-1}, the meteoric water (MW) end-members 0 PSU, -19.5 $\permil$ and 1620 μmol kg^{-1}, and the saline Pacific Summer Water (f_{PSW}) end-members 31.5 PSU, -3.0 $\permil$, 2250 μmol kg^{-1}, for S, $\delta^{18}O$ and \textit{TA}, respectively. The Mackenzie River represents the major source of meteoric water on the Mackenzie shelf.

\subsection{Additional environmental data}
To describe ocean currents, temperature, and salinity near the shelfbreak, ~~we used,~~ in addition to CTD casts~~,~~ we used data from a current meter (RCM11, Aanderaa Instruments) moored at station CA05 near the center of Line 100 (Fig. ~~1).~~\ref{fig:MAP}). The locations where the mooring CA05 was deployed and the depth of the current meter varied slightly between years. During season 2003--2004, it was deployed in 250

m deep water (71.42° N, 127.37° W) at a depth of 202 m. In 2007--2008 and 2008--2009, the bottom depth was about 200 m (71.31° N, 127.60° W) and the instrument depth 178 m. In addition to current speed and direction, the instrument recorded water temperature, conductivity, turbidity, and dissolved oxygen content, all at 0.5 hour intervals. The conductivity sensor did not function in 2007--2008. ~~For the 2008--2009 season, there was additionally a CT sensor (RBR Ltd.) with an integrated turbidity sensor (Seapoint Sensors, Inc.) deployed at a depth of 57 m from the surface and recording data at 10-minute intervals.~~

Annual estimates of Mackenzie River discharge and ice concentrations on the Canadian Beaufort Sea shelf for years 2004, ~~2007,~~ 2008, and 2009 were obtained from publicly available data provided by Environment Canada. Daily discharge rates (in units of ~~m3~~m^3 s^{-1}) for the Mackenzie River at the Arctic Red River location (10LC014) were obtained from Water Survey of Canada (Environment Canada) hydrometric data online archives. Ice coverage with a 1-week resolution for the Mackenzie Shelf area was calculated using the IceGraph 2.0 program (region: cwa01_02) provided online by the Canadian Ice Service (Environment Canada).

Estimates of wind speed over the shelf were obtained by averaging 10-m elevation wind data over grid points located over the shelfbreak in the southeastern Beaufort Sea obtained from National Centers for Environmental Prediction (NCEP) (Fig. ~~1).~~\ref{fig:MAP}). As pointed out by Williams et al. (2006), NCEP data are readily available and may be preferable over observations made at coastal stations because the latter may be affected by the presence of land. We use the NCEP wind data in a qualitative sense to identify conditions that may have induced upwelling or downwelling of seawater within the shelf area \citep[e.g.,][]{Kirillov_etal_2016}.

\section{Results and Discussion}
\subsection{~~Overview of water characteristics in August 2009}~~
~~\subsubsection{~~Water mass distributions~~}~~
 and circulation during August 2009}
During the MALINA cruise in August 2009, there was a distinct east-west gradient in the observed surface salinity on the shelf (Fig. ~~2~~\ref{fig:SSURF}a). To the west, surface salinities below 24 PSU were caused by the presence of the river plume that flowed along the coast and over the Mackenzie Trough in response to easterly winds during June 2009~~.~~ (see section 3.3.3). The river plume formed a near-surface layer of about 15--20 m thickness, which covered the full extent of line 600 and line 700. To the east, water with salinity above 29 PSU was observed to reach the surface in the area north of Cape Bathurst. \citet{Williams_Carmack_2008} described such upwelling from within the Amundsen Gulf as topographically induced in response to easterly winds. Salinity values in excess of 32 PSU were measured near the shelf bottom at 30 m (Fig. ~~2e~~\ref{fig:SSURF}c), which correspond to Pacific ~~waters~~Waters in Amundsen Gulf at a depth of about 80 m (Fig. ~~2e~~\ref{fig:SSURF}e). Generally, for the ~~Canadian Beaufort Sea~~Arctic Ocean, salinity controls the vertical stratification such that higher salinity is found at greater depth.

The water mass definition that ensues follow \citet{Carmack_etal_1989} and are consistent with descriptions in \citet{Lansard_etal_2012} and \citet{Matsuoka_etal_2012}.
The salinity range between 30.7 and 32.3 PSU corresponds to the Pacific Summer Water mass, which ~~as the name suggests~~ originates from waters flowing through Bering Strait during summer~~ \citep{Carmack_eta_1989, Matsuoka_etal_2012}.~~. Underneath, the Pacific Winter Water is characterized by salinity between 32.3 and 33.9 PSU and typically found from $\sim$180 to 220 m depth~~.~~ \citep[e.g.,][]{Jackson_etal_2015}. This is followed by a transition to waters of Atlantic-origin with salinity > 34.7 and temperature above 0 $^{\circ}$C typically found between $\sim$220 and 800 m. Cold and dense deep water are found at greater depths and down to the bottom.

The relative contributions ($\%$) of the two sources to the freshwater content, i.e., meteoric water f_{MW} and sea ice meltwater f_{SIM}, in the surface layer is shown by the contours in Fig. \ref{fig:SSURF}a. The percent values are calculated as follows: $f_{MW}/(f_{MW}+f_{SIM})\times100$. Apart from the Mackenzie River mouth, the freshwater in the surface layer was a mixture between sea ice melt and river runoff. River water prevailed along the coastline, while sea ice melt had a larger contribution further offshore. A larger river water fraction also extended further along the west coast with the northwest flowing river plume. In the upwelling region north of Cape Bathurst, river runoff and ice melt contributed about equal amounts to the relatively small freshwater content of $\sim$10 \%. The high ice melt proportions in excess of 80 \% were found in offshore waters with melting multiyear sea ice \citep{Belanger_etal_2013}.

Geostrophic currents for the cross-shelf sections 100, 200, 300, and 600 were calculated using temperature and salinity data from August 2009 CTD casts (Fig. \ref{fig:GEOSTROPHIC}). The reference depth, where the current velocity was assumed to be zero, was selected as 500 m, corresponding to a water mass originating in the Atlantic in which geopotential gradients are small \citep{McPhee 2013}. The sections reveal a westward mean flow of up to 9 cm s^{-1} in the Canada Basin (Fig. \ref{fig:GEOSTROPHIC}b, c), which is consistent with the anticyclonic circulation of the Beaufort Gyre. Similarly, currents over the shelf were typically westward with speeds on the order of a few centimeters per second. A notable feature was the presence of the eastward flowing shelfbreak current centered between 100 and 150 m depth \citep{Pickart_2004}.
The shelfbreak current is an indicator for downwelling flow from the shelf to the basin \citep{Dmitrenko_etal_2016}.
Both \citet{Dmitrenko_etal_2016} and \citet{Forest_etal_2015} present mooring data collected at Mackenzie Shelf shelfbreak location showing events of wind-driven shelfbreak current intensifications (with flow up to 1.2 m s^{-1} in January 2005) during downwelling favorable winds. However, to our knowledge, the current intensification along the Mackenzie Shelf shelfbreak during summer has not been shown in the literature to date. The mean easterly flow was around 3 cm s^{-1} (Fig. \ref{fig:GEOSTROPHIC}a--c), which is consistent with the observations of \citet{Pickart_2004} for the summertime period along the Alaskan Beaufort shelfbreak. The section along line 600 in the Mackenzie Trough captured

an anticyclonic mesoscale eddy ($\sim$50 km diameter) which impacted the patterns of $c_\mathrm{p}(660)$ and chl-\textit{a} fluorescence (see below).

\subsection{Characteristics of particles suspended in seawater in August 2009}
Empirical relationships between the beam attenuation coefficient and SPM are dependent on the composition and size distribution of particle assemblages \citep{Kitchen_etal_1982, Bunt_etal_1999, Babin_etal_2003b, Reynolds_etal_2010, Wozniak_etal_2010, Hill_etal_2011}.
In this section we present several water characteristics encountered in August 2009 that help understand the origin of suspended particles and composition of particle assemblages in the Canadian Beaufort Sea. The absorption associated with organic and inorganic material is described elsewhere \citep{Doxaran_etal_2012, Belanger_etal_2013}. However, the measured particulate absorption at 660 nm was found to be smaller by 1--4 orders of magnitude than $c_\mathrm{p}(660)$ (data not shown).

~~\subsubsection{Beam attenuation and fluorescence}~~
Particle size distributions during MALINA and the relationship to backscattering are described in \citet{Reynolds_etal_2016}.The environmental conditions encountered during MALINA showed large spatial variability; yet, a statistically significant and strong correlation was found between the particulate beam attenuation coefficient ($c_\mathrm{p}(660)$) and SPM, as well as POC (see section \ref{relationship}). Although we recognize the possibility of interannual and seasonal variability in particle characteristics, the wide range of particle characteristics observed during the MALINA expedition gives us confidence in the applicability of the derived statistical relationships to infer suspended particle concentration fields on the Mackenzie Shelf and southeastern Beaufort Sea.

Generally, $c_\mathrm{p}(660)$ in the near-surface layer ~~$c_\mathrm{p}(660)$~~ decreased from > 1 m^{-1} in coastal waters to < 0.02 m^{-1} in offshore Canada Basin waters (Fig. ~~2),~~\ref{fig:SSURF}), reflecting the riverine and coastal sources of particulate matter. To the west, the fresher surface layer influenced by the river plume featured relatively high $c_\mathrm{p}(660)$ ranging from 0.1 to 0.4 m^{-1} (Fig. ~~2b~~\ref{fig:SSURF}b) and high ~~colored~~coloured dissolved organic matter (CDOM) fluorescence \citep[Fig. ~~3;][]~~\ref{fig:FLUO};][]{Matsuoka_etal_2012}. The highest ship-based observation of surface-water $c_\mathrm{p}(660)$ of $\sim$2.6 m^{-1} was observed at station 394 in 13-m deep waters at the mouth of Kugmallit Bay; however, $c_\mathrm{p}(660)$ reached 8.8 m^{-1} at 10 m depth and presumably higher values near the seabed. The surface waters in the area of upwelling just north of Cape Bathurst appear also to have been a hotspot in terms of particle concentration; $c_\mathrm{p}(660)$ at the surface of station 170 reached values over 1.2 m^{-1} (Fig. ~~2b).~~

\ref{fig:SSURF}b).

The high $c_\mathrm{p}(660)$ values near the shelf seafloor in August 2009 were accompanied by a strong chl-\textit{a} fluorescence signal, both of which also extended from the shelf far into the Canada Basin as a subsurface chl-\textit{a} maximum (SCM) layer (Figs. 3a\ref{fig:FLUO}a, c, e). The SCM layer is a consistent feature in the southern Beaufort Sea during summer \citep{Martin_etal_2010}. The SCM was centered at depths between the 31.5 and 32.3 PSU isohalines, which corresponds to the lower portion of the Pacific Summer Water. The underlying Pacific Winter Water is characterized by maxima in both nutrients and CDOM \citep[Fig. 3;][]\ref{fig:FLUO};][] {Matsuoka_etal_2012}. The nutrient maximum is typically found at the center of the Pacific Winter Water near the 33.1 PSU isohaline \citep{Martin_etal_2010}.

\subsubsection{Particulate matter composition and size distribution} Empirical relationships between the beam attenuation coefficient and SPM are dependent on the composition and size distribution of particle assemblages \citep{Kitchen_etal_1982, Bunt_etal_1999, Babin_etal_2003b, Reynolds_etal_2010, Wozniak_etal_2010, Hill_etal_2011}, and may thus show regional differences. The proportion of organic to inorganic material is important because mineral particles have typically higher refractive index compared to organic particles, and thus generally produce higher scattering \citep[e.g.,][]{Babin_etal_2003b, Wozniak_etal_2010}. Beam attenuation is also affected by variable absorption. In particular, at 660 nm the absorption by chlorophyll pigments may cause important distinctions between organic and inorganic material \citep{Doxaran_etal_2012, Belanger_etal_2013}. Particle size is of importance because the scattering cross-section of individual particles typically increases as particle size increases \citep{Morel_Bricaud_1986, Stramski_Kiefer_1991}. However, particle concentration often decreases significantly with an increase in particle size so that relatively small particles can have higher contribution to bulk scattering per unit mass concentration of particles than larger particles \citep{Babin_etal_2003b, Reynolds_etal_2010, Hill_etal_2011}. In this section, we provide a description of the bulk composition and size distribution of particle assemblages sampled during the MALINA cruise in August 2009. The absorption associated with organic and inorganic material is described elsewhere \citep{Doxaran_etal_2012, Belanger_etal_2013}. However, the measured particulate absorption at 660 nm was found to be smaller by 1--4 orders of magnitude than $c_\mathrm{p}(660)$ (data not shown).

Following \citet{Wozniak_etal_2010}, the data representing discrete seawater samples were partitioned into three composition-related groups based on the POC/SPM ratio: 1) mineral-dominated when POC/SPM < 0.06, 2) mixed when 0.06 $$\leq$ POC/SPM $$\leq$ 0.25, and 3) organic-dominated when POC/SPM > 0.25. Only onat station 394 (13 m bottom depth) near the entrance to Kugmallit Bay did the CTD/Rosette sampling from the \textit{CCGS Amundsen} take place sufficiently close to the coast to reach the mineral-dominated water masses. However, the results from barge sampling in August 2009 show that mineral-dominated particle composition was mostly limited to shallow waters less than about 20 m deep near the two Mackenzie River mouths (Fig. 4a).where f_{MW} contributed > 90 \% of the freshwater content (Fig. \ref{fig:POC2SPM}a). This agrees with past observations suggesting that most mineral-dominated particles transported by the Mackenzie River plume settle to the bottom within the delta or shortly after reaching the shelf where the plume speed decreases \citep{Macdonald_etal_1998}. For the rest of the shelf and basin surface waters the particle composition in our collected samples showed considerable variability within the organic-dominated and mixed types (Fig. 4).\ref{fig:POC2SPM}). The one exception was, however, the surface sample at station 110 located furthest east in the Amundsen Gulf where the POC/SPM was less than 0.0175 (SPM = 3.56 g m^{-3}). Although the possibility of contamination of the sample from station 110 cannot be excluded, the high SPM load could also have been caused by the release of ice-rafted sediments as the ice melted \citep{Belanger_etal_2013}. Deteriorated multiyear ice was observed in the vicinity of the station 110, which could have been the source of minerogenic material.

Sea ice meltwater was found to have a slightly larger contribution at station 110 compared to other stations along line 100 (Table 1).

For a detailed description of the particle size distribution (PSD) data measured during MALINA, readers are referred to \citet{Reynolds_etal_2016}. Here, we provide an overview of the spatial distribution of the PSD by calculating the volume fraction of particles less than 1 μm in diameter D to the total particle volume between 0.7 μm and 120 μm. A notable feature in the particle volume distribution, $V(D),)$, was the presence of high concentrations of small particles with diameters D < 1 -µm< 1 μm volume fractions in surface waters and their reduced abundance in subsurface waters (Fig. 4b\ref{fig:POC2SPM}c). The highest increase in the abundance of submicron particles relative to larger particles was found in samples collected furthest to the west along lines 600 and 700 where surface water salinity associated with the river plume was less than 24 PSU. SimilarA similar observation also pertains to the surface water sample from station 380 located near the Mackenzie River,Äôs Kugmallit Bay channel., even though the salinity was $\sim$28 PSU (Fig. \ref{fig:POC2SPM}c). However, the fraction of meteoric water was similar to station 620 (Fig. \ref{fig:POC2SPM}d). The PSD measurements for low salinity, highly turbid samples nearest to the river mouth (stations 390, 394, and 690) were not possible with the Coulter technique. Interestingly, the offshore samples from stations 110 (surface) and 240 (55 m depth) with low POC/SPM ratios were also associated with high concentrations of < 1 μm particles, which is consistent with multiyear ice (suspension freezing) and shelf bottom (resuspension) origins. The volume fraction of < 1 μm particles for the surface water samples at station 240 and the nearby station 235, was 0.12 and 0.18, respectively. At these stations, the near-surface salinity was close to 27.5 PSU.due to limitations of the Coulter technique. Station 110 stands out among line 100 stations with < 1 μm volume fractions of 0.29 at the surface (salinity of 29.1 PSU) and 0.09 at 60 m depth (31.6 PSU).

In general, the samples for which PSD was measured can be separated based on salinity of the sampled water. The samples with salinity < 30 PSU were collected in the surface layer while the samples with salinity > 30 PSU were collected at a depth of 20 m or deeper. Percentile statistics of V(D) show that small sized particles dominated the particle assemblages within surface waters. The subsurface waters were characterized by larger variability with generally increased contribution of larger particles (data not shown). The particle diameters corresponding to the 10th, 50th, and 90th percentiles of V(D), i.e., D_V^{10}, D_V^{50}, and D_V^{90}, respectively, can be summarized as follows: D_V^{10} was

~~within the range 0.71--0.74 μm for salinities < 30 PSU and 0.72--0.98 μm for salinities > 30 PSU; D_V^{50} was in the range 0.78-1.47 μm for salinities < 30 PSU and 1.01--9.45 μm for salinities > 30 PSU; and D_V^{90} was in the range 1.04--15.38 μm for salinities < 30 PSU and 7.96--29.64 μm for salinities > 30 PSU. D_V^{90} showed the smallest differentiation between surface and subsurface waters and a noticeable increase as a function of increasing salinity, which could indicate particle aggregation.~~

To conclude, from the data in Fig. \ref{fig:POC2SPM} we find that (1) when f_{MW} increased in the surface waters of southeast Beaufort Sea, POC/SPM ratios decreased while the < 1 μm particle fraction increased, and conversely (2) when the f_{SIM} influence increased, POC/SPM increased while the < 1 μm particle fraction decreased in surface waters.

\subsection{Relationships between SPM, POC and particulate beam attenuation}
 \label{relationship}
The SPM of the samples examined during the MALINA cruise ranged from 0.04 to 140 g m^{-3} with associated POC from 0.007 to 1.5 g m^{-3} \citep{Doxaran_etal_2012}. Organic-dominated and mixed particle assemblages were predominant in the portion of the data set obtained from ~~the \textit{CCGS Amundsen}~~ship-based sampling, with SPM extending to 5.6 g m^{-3}. The mineral-rich particle assemblages were more common in turbid estuarine waters located close to shore~~.~~ (Fig. \ref{fig:POC2SPM}a). These waters were sampled using a small barge with an optical package that included a Wetlabs AC-9 meter \citep{Doxaran_etal_2012}, but no Wetlabs C-Star 660-nm. The nearest wavelength band on the AC-9 was 676 nm. It thus provided $c_\mathrm{p}(676)$. Note that much higher sediment loads were observed in the region in the past. For example, \citet~~[][, ~~[][their Fig. 10]{Carmack_Macdonald_2002} reported on near bottom SPM values of 3000 g m^{-3} due to resuspension of bottom sediments during a storm in September 1987.

Data from all 28 stations with coincident measurements were used in the development of relationships between $c_\mathrm{p}(660)$ and SPM and between $c_\mathrm{p}(660)$ and POC. The particulate beam attenuation coefficient correlated well with both SPM and POC (Fig. ~~5a, b). Three types of regression analysis for SPM vs. $c_\mathrm{p}(660)$ and POC vs. $c_\mathrm{p}(660)$ were evaluated: (i) a linear fit, (ii) a linear fit to log-transformed data, and (iii) a nonlinear power function fit using the Levenberg-Marquardt optimization algorithm. For the SPM vs. $c_\mathrm{p}(660)$ the differences between the three types of regressions are not significant in terms of the determination coefficient (r^2) which was 0.711 for the linear fit and 0.713 for the other fits. However, the nonlinear power function fit appears to best match the SPM vs. $c_\mathrm{p}(660)$ data. This is supported by reasonably good values of both the root mean square error (RMSE = 0.421 g m^{-3}) and mean normalized bias (MNB = 13.7 \%). MNB and RMSE were calculated following equations in Stramski et al. (2008). For comparison, these values were: RMSE = 0.421 g m^{-3} and MNB = 26.0 \% for linear fit, and RMSE = 0.457 g m^{-3} and MNB = 11.1 \% for linear fit based on log-~~

~~transformed data. Therefore, we selected the SPM vs. $c_\mathrm{p}(660)$ relationship obtained from nonlinear least squares regression as an algorithm for estimating SPM in [g m^{-3}] from $c_\mathrm{p}(660)$ in [m^{-1}] in the rest of this study:~~
\ref{fig:FIT}a, b).
\begin{equation}
\mathrm{SPM} = 1.933 \: c_\mathrm{p}(660)^{0.9364}
\end{equation}

~~The regression analysis of POC vs. $c_\mathrm{p}(660)$ data yielded the best results for linear fit to log-transformed data: r^2 = 0.744, RMSE = 0.0449 g m^{-3}, and MNB = 8.72 \%. These statistics are, however, only slightly better compared with the other two regression analyses (linear fit: RMSE = 0.0459 g m^{-3} and MNB = 36.16 \%, nonlinear power function fit: RMSE = 0.0436 g m^{-3} and MNB = 22.7 \%). Hence, for POC we recommend the algorithm obtained from a linear regression to log-transformed data:~~
and
\begin{equation}
\mathrm{POC} = 0.2071 \: c_\mathrm{p}(660)^{0.6842}
\end{equation}
where SPM and POC ~~is~~are in [g m^{-3}] and $c_\mathrm{p}(660)$ in [m$^{-1~~}$].~~}$], with r^2 of 0.71 and 0.74, respectively. Further details on the evaluation of the regression fits are provided in the Supplementary Material. In some instances, for example in biogeochemical modelling studies, the objective may be to estimate light transmission from SPM or POC that has either been measured or is available as model output. The counterparts of Eqs. 2 and 3 are: $c_\mathrm{p}(660)$ = 0.4267 SPM$^{0.9068}$ and $c_\mathrm{p}(660)$ = 3.088 POC$^{1.098}$, respectively.

The slopes of the best fit lines (with intercepts set to zero) obtained through linear fitting to all pairs of $c_\mathrm{p}(660)$ vs. SPM and $c_\mathrm{p}(660)$ vs. POC data were 0.404 m^2 g^{-1} ~~(~~($r~~$^~~^2$ = 0.70) and 3.39 m^2 g^{-1} ~~(~~($r~~$^~~^2$ = 0.72), respectively. These slope values represent average SPM-specific and POC-specific particulate beam attenuation coefficients, respectively, for the examined data set. Our average SPM-specific particulate beam attenuation coefficient at 660 nm is consistent with the range 0.2--0.6 m^2 g^{-1} reported by \citet{Boss_etal_2009} and \citet{Hill_etal_2011} for a 12-m deep coastal site in the North Atlantic Ocean (Martha,Äôs Vineyard, MA, USA). Our average POC-specific value is near the middle of the range from 2.31 m^2 g^{-1} at $c_\mathrm{p}(660)$ = 0.45 m^{-1} to 4.10 m^2 g^{-1} at $c_\mathrm{p}(660)$ = 0.07 m^{-1} observed by \citet{Stramska_Stramski_2005} in the north polar Atlantic. \citet{Jackson_etal_2010} reported beam attenuation vs. SPM and POC correlations for measurements in the Arctic Ocean in 2006--2007, from which we estimate SPM-specific values of 0.34-0.50 m^2 g^{-1} and POC-specific values of 3.4--3.7 m^2 g^{-1} for the $c_\mathrm{p}(660)$ range from 0.07 to 0.45 m^{-1}, respectively. The slopes calculated from our data within this same $c_\mathrm{p}(660)$ range were 0.46 m^2 g^{-1} ~~(~~($r~~$^~~^2$ = 0.57) for $c_\mathrm{p}(660)$ vs. SPM and 2.47 m^2 g^{-1} ~~(~~($r~~$^~~^2$ = 0.69) for $c_\mathrm{p}(660)$ vs. POC, with the latter being consistent with other datasets

\citep[e.g.,][]{Cetinic_etal_2012} but notably smaller than the \citet{Jackson_etal_2010} value.

The data of SPM used in fitting the relationship of SPM vs. $c_\mathrm{p}(660)$ range from about 0.04 g m^{-3} to 5.6 g m^{-3} (Fig. ~~5a~~\ref{fig:FIT}a). This corresponds to $c_\mathrm{p}(660)$ values up to about 3.1 m^{-1}; however, the highest measured $c_\mathrm{p}(660)$ where Wetlabs C-Star measurements were made (but not accompanied by SPM sampling) was 8.8 m^{-1} (at 10 m depth at station 394), which according to Eq. 2 would correspond to SPM of about 14.8 g m^{-3}. For the purpose of examining SPM patterns we extend the use of Eq. 2~~ to extend~~ beyond the maximum measured SPM. A similar non-linear least squares regression analysis that included the highest observed SPM values and corresponding beam attenuation values measured at 676 nm using a Wetlabs AC-9 resulted in a very good fit and a trend line approximating that of the extrapolation of Eq. 2 (Fig. ~~5c~~\ref{fig:FIT}c). This supports the assumption that the estimation of SPM from beam attenuation measurements can be reasonably well extended to cover the broader range of values measured with the Wetlabs C-Star, thus being valid from the very clear open ocean to the highly turbid estuarine waters.

The situation is different for the POC vs. $c_\mathrm{p}(676)$ regression. Coincident observations of POC and $c_\mathrm{p}(676)$ reveal a tendency of POC to level off at the very high attenuation values (Fig. ~~5d~~\ref{fig:FIT}d). These high $c_\mathrm{p}(676)$ values were all observed from the barge in the shallow estuarine waters of the Mackenzie River mouth \citep{Doxaran_etal_2012}. As the particle assemblages within these coastal waters are dominated by mineral particles, a weak relationship between POC and c_p is expected. However, within the POC range up to about 0.45 g m^{-3} and $c_\mathrm{p}(660)$ $\leq$ 3 m^{-1} covered by ship-based observations (Fig. ~~5b~~\ref{fig:FIT}b), which included only organic-dominated and mixed particle assemblages (POC/SPM $\leq$ 0.~~06~~25), both $c_\mathrm{p}(660)$ and $c_\mathrm{p}(676)$ are well represented by Eq. 3. This covers the range of $c_\mathrm{p}(660)$ observed along all the ~~transect shown in ~~ship-based transects (Fig. ~~1.~~

\ref{fig:MAP}).

\subsection{SPM distributions on the shelf, slope and beyond}
The large range in concentration and composition of suspended particle assemblages (Figs. ~~4~~\ref{fig:POC2SPM} and ~~5)~~\ref{fig:FIT}) collected as a part of the MALINA dataset allowed the determination of empirical relationships for estimating SPM and POC from $c_\mathrm{p}(660)$ (Eqs. 2--3) in Canadian Beaufort Sea waters. In the following, SPM distributions in the Canadian Beaufort Sea are investigated by applying the SPM algorithm to $c_\mathrm{p}(660)$ data collected during ~~four~~three cruises in the Canadian Beaufort Sea. These cruises include the two year-long projects CASES ~~project in ~~(2003-2004~~, the ArcticNet cruise in 2007, the ~~) and IPY,ÄìCFL ~~study in ~~(2007-2008~~,~~), and the MALINA project in August 2009, which altogether cover a wide range of conditions encountered during the open water season in Canadian Beaufort Sea. ~~First, in section 3.3 the environmental forcing and oceanographic conditions during each of these expeditions are described, and then in section 3.4 the observed patterns of the SPM fields are presented and discussed in~~

~~the context of these conditions. Furthermore~~ Additionally, $c_\mathrm{p}(660)$ data from four deep casts in Canada Basin collected during the JOIS expedition in September 2009 are examined to show conditions further away from the shelfbreak (Fig. \ref{fig:MAP}).

Here, we focus on the cross section plots for transect lines 100, 300 and 600 only (Fig. \ref{fig:MAP}). These transect lines have been also repeatedly measured during other field campaigns \citep[e.g.,][]{Carmack_etal_1989, Tremblay_etal_2011, Lansard_etal_2012, Mol_etal_2018}. Line 100 crosses the Amundsen Gulf near its entrance from north of Cape Bathurst towards the southwestern point of Banks Island. Line 300 is a south-to-north transect located approximately along 134° W, and associated with Kugmallit Valley. Line 600 follows the Mackenzie Trough and provides the western border to the Mackenzie shelf. The Mackenzie River delta is a maze of tributaries; however, the main discharge channel exits at Mackenzie Bay near the end of line 600, while the second largest channel exits at Kugmallit Bay near line 300.

Figure \ref{fig:SPM} shows the SPM fields from the three expeditions, derived from $c_\mathrm{p}(660)$ profiles using Eq. 2. Figure \ref{fig:TS} provides the supporting temperature and salinity fields. Black contour lines show SPM values up to 10 g m^{-3} (Fig. \ref{fig:SPM}f). We recall from section \ref{relationship} that both Eq. 2 and Eq. 3 are derived from ship-data and are strictly valid for $c_\mathrm{p}(660)$ values up to 3.1 m^{-1} (Fig. \ref{fig:FIT}). Thus, this excludes the most mineral-dominated waters on the shelf with SPM over 5.6 g m^{-3} and POC over about 0.5 g m^{-3}. However, comparisons against near-shore data collected with the barge indicates that Eq. 2 for SPM is reasonably valid for a wider range (Fig. \ref{fig:FIT}c). This is not the case for POC. Within the valid range ($c_\mathrm{p}(660)$ < 3.1 m^{-1}) the presented SPM [g m^{-3}] fields can be converted to POC [g m^{-3}] according to POC $= 0.1279$ SPM$^{0.7307}$, which is derived from the regression analysis of POC vs. SPM data.

Elevated SPM values were generally present in shelf surface waters, and associated with a lower salinity surface layer or plume. Highest values were seen nearest to the shore in shallow waters, indicating the riverine origin. SPM decreased past the shelfbreak often reaching very low values, except within the northwest flowing Mackenzie River plume during the 2004 CASES and 2009 MALINA expeditions (Figs. \ref{fig:SPM}g, h). Clear waters with SPM ranging between 0.04 and 0.06 g m^{-3} were found offshore on line 300 in each of the three expeditions (Figs. \ref{fig:SPM}d--f). The corresponding POC ranged from 0.01 to 0.02 g m^{-3}. The low SPM values were especially widespread in August 2009 likely related to the high f_{SIM} content (Table 1).

Wedges of very clear water are seen extending far onto the shelf particularly during 2009. The extension of clear waters onto the shelf as a wedge between the surface plume and the turbid near bottom layer has been described by \citet{Carmack_etal_1989}. It appears that neither particle settling from the surface plume nor the resuspension of bottom sediments were sufficient in August 2009 to increase these clear-water values of $c_\mathrm{p}(660)$ above those found in deep basin surface waters. The landward extension of the clear-water layer was particularly noticeable on line 600 (Fig. \ref{fig:SPM}h) which corresponds to the Mackenzie Trough, the main river channel and the most distinct surface plume feature of the transects.

Figure \ref{fig:SPM} reveals a ubiquitous presence of subsurface nepheloid layers extending from the Beaufort Sea continental slope. These nepheloid layers are produced primarily by resuspension of bottom sediments settled onto the shelf or slope, and provide evidence for the transport of suspended particles and water away from the shelf. In the Mackenzie Trough (line 600), two subsurface nepheloid layers (in addition to the surface river plume) were observed in 2004 and 2009 to extend from the shelf at depths of 100--130 m and 200--250 m (Fig. \ref{fig:SPM}g, h). These two layers formed near where the 33.1 PSU isohalines intersected the shelf seafloor and immediately above and below a slightly less sloping section of the Mackenzie Trough bottom. However, only the upper layer was accompanied by relatively high chl-\textit{a} fluorescence (Fig. \ref{fig:FLUO}e). The depths of 100 m and greater are beneath the euphotic layer rendering primary production negligible. Thus, these chl-\textit{a} containing particles likely represent transported particles that originated from resuspension in shallower shelf waters.

\subsubsection{Subsurface chl-\textit{a} maximum}
It is important to differentiate the nepheloid layers from the mainly locally formed subsurface chl-\textit{a} maximum (SCM) layer that is commonly present in the Canadian Beaufort Sea \citep{Martin_etal_2010, Tremblay_etal_2011}. As the SCM seems to intersect with the shelf bottom before extending into the Canada Basin (Fig. \ref{fig:FLUO}), the presence of relatively high chl-\textit{a} concentrations within subsurface nepheloid layers may however conceal the presence of minerogenic particles at the same depth. As suggested by \citet{Tremblay_etal_2011}, the patterns of salinity, $c_\mathrm{p}(660)$ and chl-\textit{a} fluorescence indicate that biological production on the shelf bottom was enhanced by upwelled nutrient-rich waters and, at the time of our measurements, biogenic material was being transported seaward in an intermediate nepheloid layer across the shelfbreak at 50--70 m depth (Figs. \ref{fig:FLUO} and \ref{fig:SPM}c, f, g). The shelf circulation at play makes it conceivable that the transport of biogenic material produced on the shelf, including resuspension of settled particles originating from an earlier bloom (e.g. ice algae), could play a role in the formation and maintenance of the SCM in the off-shelf region.

\subsubsection{Deep waters}
Numerous intermediate nepheloid layers (INLs) are seen in the upper 500 m of the water column throughout the Amundsen Gulf and extending into Canada Basin (Fig. \ref{fig:SPM}). The variability in the depth locations of these INLs is large between the profiles (Fig. \ref{fig:deepSPM}). Generally, the SPM of INLs in offshore waters was an order of magnitude smaller than in the benthic nepheloid layer (BNL) on shelf and particle concentrations decreased with distance from the shelf.

Beneath 500 m depth, the vertical profiles of SPM still showed numerous inversions (Fig. \ref{fig:deepSPM}). Generally, however, the particle concentration at specific depths decreased as bottom depth increased as it also relates to the distance from the shelfbreak. This decrease is approximately exponential with distance from the shelfbreak. In waters less than 3000 m deep located on the continental slope and rise, the SPM began to increase with depth from about the mid depth of the water column which had the clearest waters. The thickness of these BNLs ranged from $\sim$200 m (station 340) to over 1000 m (Fig. \ref{fig:deepSPM}). Past the 3000 m bottom depth, BNLs were essentially absent with the clearest waters found close to the bottom as may also be the case for the Canada Basin abyssal plain \citep{Hunkins_etal_1969}. Near-bottom SPM values based on $c_\mathrm{p}(660)$ were $\sim$2$\times$10^{-3} g m^{-3} at the station CB-27, and decreased to $\sim$1$\times$10^{-3} g m^{-3} at 3500 m at CB-21 (74.0042° N, 139.8699° W, i.e., 113 km north of CB-27) on 9 October. Thus, basin waters agreed with the two types of profiles described in \citet{Hunkins_etal_1969}, first, in waters with bottom depths less than about 3000 m the SPM had minimum values roughly at mid-depths of the water column and then increased towards the bottom forming a c-shaped profile, and second, in waters exceeding the 3000 m depth the SPM reached minimum values near the bottom.

A notable INL at stations CB-23, CB-27, and CB-21 was spreading in the layer immediately below the isopycnal surface where the potential density anomaly $\sigma \theta$ reached 28.096 kg m^{-3} or the salinity reached 34.956 (Fig. \ref{fig:deepSPM}). This was the deepest INL (below which no INLs were seen) extending to the Canada Basin abyssal plain at the top of the adiabatic Canada Basin bottom water layer at $\sim$2500--2700 m depth \citep{Timmermans_etal_2003}. The depth where the INL occurred varied between the stations.

The maximum SPM within the INL at station CB-23 was 0.0126 g m^{-3} at 2470 m depth. At CB-27 the maximum was 8.2$\times$10^{-3} g m^{-3} at 2600 m (Fig. \ref{fig:deepSPM}). The SPM levels above the INLs (with $\sigma \theta$ = 28.095) were 0.010 and 0.027 g m^{-3}, respectively. Given that the INL depth increased by 130 m over the 128 km distance that separated the two stations, the INL descent rate was about 1 m km^{-1}. A thinner (50 m thick) and weaker INL with a maximum SPM of 3.2$\times$10^{-3} g m^{-3} at 2656 m was observed at CB-21 (Fig. \ref{fig:deepSPM}d). Beneath this interface the potential temperature was uniform with depth, thereby marking a transition to the adiabatic Canada Basin bottom water layer \citep[e.g.,][]{Timmermans_etal_2003}. Assuming that the particles in the INL were from the bottom layer of CB-31 (~1920 m depth with $\sigma \theta$ = 28.093 kg m^{-3}), then the transport of particles from the bottom of station CB-31 to the INL at station CB-23 requires a 560 m increase in depth over a 100 km distance, which implies a sinking rate of 5.6 m km^{-1}. Such transport of particles crosses isopycnal surfaces, suggesting the predominant role of particle settling in addition to advective transport. ~~1).~~

\subsection{Environmental forcing and oceanographic conditions}
\label{conditions}
As is evident, SPM is not a conservative property of a water mass, but undergoes settling or resuspension at rates that are dependent on

particle composition and size, and water dynamics. Consequently, in this section, the environmental forcing and oceanographic conditions during each of the three expeditions are first described and contrasted. Then, in the next section \ref{ice-melt}, the observed patterns of the SPM fields are compared and discussed in the context of these oceanographic conditions, and in particular as these patterns relate to river runoff, sea ice melt, and wind.

\subsubsection{River discharge and sea ice conditions}
The Mackenzie River discharge has large seasonal and interannual variability \citep[e.g.,][]{McClelland_etal_2012}. Similarly, sea ice concentration on the shelf undergoes large variability \citep{Galley_etal_2008}. This is also evident when comparing daily Mackenzie River discharge rates and ice concentrations on the shelf for years 2004, ~~2007,~~ 2008 and 2009 (Fig. ~~6).~~\ref{fig:RD-SIC}). Although the seasonal trend follows a predictable overall pattern, discharge rates during the open water season show significant day-to-day variation, while the timing of landfast ice break-up, wind forcing, and the large-scale circulation ~~of~~in the Beaufort ~~Gyre~~Sea affect ice concentrations.

The ~~four~~three field expeditions were conducted during different times of the annual cycle with noticeable differences in the Mackenzie River discharge (Fig. ~~6).~~\ref{fig:RD-SIC}). The CASES 2004 cross-shelf transects were conducted a few weeks after ice break-up and the freshet. The spring freshet occurred later in 2004 with a sharp peak pulse that reached a higher level than during the other ~~three~~ years considered. In 2004, the discharge decreased rapidly after the freshet so that the lowest (of the four years) annually averaged discharge occurred. The condition with the highest discharge rates was encountered during the IPY-CFL 2008 transect cross section sampling as late as in early July, when ice concentrations on the shelf were unusually low (around 10 \%).

In contrast, the MALINA 2009 sampling occurred later in the season (August) with conditions ~~during August 2009 were~~ characterized by comparatively high (30 \%) sea ice concentrations on the shelf.

The ~~fresh water~~buoyant freshwater released from the melting sea ice competed for surface space with river water, thus affecting plume dynamics and ~~its~~the ability of the plume to keep particulate matter in suspension. As was also the case during CASES in June--July 2004 \citep{Lansard_etal_2012}, the freshwater composition in the surface layer on the Mackenzie Shelf during MALINA was a mixture between river runoff (meteoric water) and sea ice meltwater (Fig. \ref{fig:SSURF}a). Table 1 provides information on surface salinity and the contribution of freshwater sources measured at the same geographical locations during both CASES and MALINA. Compared to MALINA, river runoff during CASES resulted in lower surface salinity and contributed to a much larger fraction of the freshwater in the southern half of the Mackenzie Shelf. The one station 320 located past the shelfbreak, however, indicates fresher conditions during MALINA due to a higher sea ice meltwater contribution. In contrast to the river waters, sea ice ~~melt waters~~meltwater typically ~~contain~~contains little particulate matter and CDOM (e.g., compare Fig. ~~3b~~\ref{fig:FLUO}b, d, f). However, significant near-surface particle enrichment was observed, which was associated with

~~melt water~~meltwater originating from multi-year ice \citep{Belanger_etal_2013}. During MALINA~~ 2009~~, numerous multi-year ice floes had drifted into the southeastern Beaufort Sea where they were melting in place (Fig. ~~7~~\ref{fig:CIS} and Fig. S1 in Supplementary Material).

~~While the water sampling during the 2004, 2008, and 2009 field experiments occurred during the sea ice melt season, freeze-up had commenced during the ArcticNet sampling in late October 2007. Despite the generally high easterly wind speeds, new ice formation proceeded rapidly during the second half of October and had formed what appeared as a solid sea ice cover by 22 October along the coastline, largely covering the shelf, and in the offshore pack ice (Fig. 7b). The area around the shelfbreak remained open at the time, a common condition for this flaw lead polynya where delays in the fall freeze-up are often observed \citep{Galley_etal_2008}. A solid ice cover along the shore would presumably have reduced direct wind stress on surface waters, however ice motion in offshore waters may instead have contributed to the surface drag and Ekman transport \citep{OBrien_etal_2011, Spall_etal_2014}. Brine release from forming sea ice is further expected to destabilize the water column and enhance vertical mixing.~~

\subsubsection{Wind forcing}
The large freshwater inputs to the Mackenzie Shelf during summer result in strong vertical stratification and a vertically sheared two-layer circulation (Fig. \ref{fig:GEOSTROPHIC}) \citep{Carmack_Macdonald_2002, Carmack_Chapman_2003, Mol_etal_2018}. This estuarine circulation is reflected in the patterns of SPM across the shelf (Fig. \ref{fig:SPM}). Sustained easterly along-shelf winds, particularly when strong, are known to cause ~~shelf surface waters to move~~ offshore ~~through~~ Ekman transport of shelf surface waters, thereby ~~causing~~generating upwelling of deeper nutrient rich water of Pacific-origin onto the shelf \citep{Carmack_Kulikov_1998, Williams_etal_2006, Williams_etal_2008, Yang_2009}. The high salinity observed during the MALINA expedition in Kugmallit Valley (line 300), Mackenzie Trough (line 600) and near the coast west of 140° W indicated the occurrence of upwelling (Fig. ~~2).~~\ref{fig:SSURF}). During westerly winds, onshore Ekman transport will ~~cause~~generate downwelling flow on the shelf \citep{Dmitrenko_etal_2016}. During westerly or weak winds, the river plume ~~tends~~turns right to flow ~~to the east~~eastward along the coast of Tuktoyaktuk Peninsula. Relaxation or reversal of either of these winds will cause return flow to occur towards or from the shelf. Furthermore, strong winds, and brine released from ice formation during late fall and winter, promote vertical mixing and may mix shallow shelf waters to the bottom~~, while freshwater input from either river discharge or ice melt increase vertical stability~~ \citep[e.g.,][]{Carmack_Macdonald_2002~~}. Consequently, three main wind-driven modes of flow affecting SPM patterns on the Mackenzie Shelf can be identified: circulation promoting (i) shelfbreak upwelling or (ii) shelfbreak downwelling, in combination with (iii) degree of vertical mixing of the water column.~~, Forest_etal_2007}.

The wind vectors reveal a predominance of easterly winds during our study periods in 2004, ~~2007,~~ 2008 and 2009, with often a southward component resulting in along-shelf wind component (Fig. ~~8a~~\ref{fig:VECTOR}a). High winds are found to be predominantly easterly. The predominance of easterly winds is also a driving force behind the large-scale anticyclonic circulation of the Beaufort Gyre and its ice cover. The occasional reversals of the Beaufort Gyre are related to transient synoptic weather patterns \citep{Asplin_etal_~~2009~~2012} that also affect the circulation on the shelf. ~~A~~Two notable ~~episode~~episodes of westerly winds occurred during the fall and winter seasons of 2008--2009 (October and December-January). However, typically the westerly wind events were characterized by low wind speeds.

The periods October--November 2008, December 2008--April 2009, and May--June 2009 were characterized by westerly or low wind speeds, and link to the extended periods of along-shelf current directions at the 178 m depth at mooring CA05 (Fig. \ref{fig:VECTOR}b).

The wind conditions prior to the ~~four~~ ship-based expeditions (marked by blue circles) are shown in Fig. ~~8a.~~\ref{fig:VECTOR}a. During June--July 2004 (CASES) the wind ~~speeds~~speed ranged from 2 to 8 m s^{-1} with a variable direction.~~ The sampling during October 2007 ArcticNet expedition was preceded by two weeks of strong easterly along-shelf winds in the excess of 12 m s^{-1}.~~ IPY-CFL sampling (late June and early July 2008) overlapped with CASES in terms of time of year; however, winds were notably different with a month of easterly winds prior to the sampling. The conditions leading up to the MALINA expedition in August 2009 are characterized by <10 m s^{-1} ~~upwelling inducing wind~~winds at directions inducing the upwelling in June and most of July, but with a turn to northerly winds during the first part of July, which probably were a contributing factor keeping sea ice on the shelf. Winds turned to southwesterly for the last week of July with wind speed > 8 m s^{-1}. Winds during the MALINA expedition were comparatively weak (< 6 m s^{-1}) with variable direction.

\subsubsection{Evidence of upwelling and relaxation}
Current speeds and directions were measured at 178 m depth on the CA05 mooring in 2008--2009 (and at 250 m in 2003--2004~~, and 204 m in 2007--2008~~) (Fig. ~~8b~~\ref{fig:VECTOR}b). This depth corresponded to the location of the base of the eastward flowing shelfbreak current (Fig. ~~9a).~~\ref{fig:GEOSTROPHIC}a). The currents at this depth on the slope were found to have two distinct modes: (i) along-shelf current that followed the isobaths towards southwest (i.e., $\sim$140°), and (ii) cross-shelf current ($\sim$300°). Interestingly, the shift between the two modes was very brief occurring within only a few hours.

As mentioned in the previous section, the long periods of along-shelf currents during 2008-2009 were related to weak or westerly winds (Fig. \ref{fig:VECTOR}a). Episodes with cross-shelf currents occurred on five occasions in the period between August 2008 and October 2009. In addition, a brief period of change in direction occurred ~~in early~~during late July and the first few days of August 2009, likely associated with the change in wind direction to southeasterly during the last week of July. The time series collected during 2003--2004 show only a minor cross-shelf flowing event around the beginning of November~~, while the 2007--2008 time series commenced during what appears to be a strong event in October--November.~~. Each episode with cross-shelf currents, with the exception of November 2003 (the location of the moored instrument was deeper and further east compared to ~~the other year~~2008--2009), was associated with increases in salinity~~ and/or~~, temperature, or both, which is an indication of upwelling. All of these events are directly linked to periods with strong easterly along-shelf winds (Fig. ~~8a~~\ref{fig:VECTOR}a) highlighting the likely role of the wind in forcing upwelling. During 2009, the salinity reached up to 34.5 PSU (Fig. ~~8d~~\ref{fig:VECTOR}d), which corresponds to an ,Äúeffective depth,Äù \citep[see Fig. 3 in][]{Carmack_Kulikov_1998} of about 300 m indicating a vertical displacement of $\sim$120 m compared to a representative offshore location. Note, however, that the recorded salinity rarely decreased below 33.5 PSU, which in itself corresponds to an ,Äúeffective depth,Äù of more than 200 m. After the abrupt termination of each upwelling event, temperature and salinity decreased towards pre-upwelling values. Some of the lowest salinity values at 178 m were encountered at the time of the MALINA expedition during August 2009, and ~~likely ~~associated with downwelling return flow~~.~~

~~\subsubsection{Geostrophic currents}~~
~~Geostrophic currents for the cross-shelf sections 100, 200, 300, and 600 were calculated using temperature and salinity data from August 2009 CTD casts (Fig. 9). The reference depth, where the current velocity was assumed to be zero, was selected as 500 m, corresponding to a water mass originating in the Atlantic in which geopotential gradients are small \citep{McPhee_2013}. The sections reveal a westward mean flow of up to 9 cm s^{-1} in the Canada Basin (Fig. 9b, c), which is consistent with the anticyclonic circulation of the Beaufort Gyre. Similarly, currents over the shelf were typically westward with speeds on the order of a few centimeters per second. A notable feature was the presence of an eastward flowing shelfbreak current centered between 100 and 150 m depth \citep{Pickart_2004}. \citet{Dmitrenko_etal_2016} presented mooring data collected at lines 200 and 300 shelfbreak locations showing an event of wind-driven shelfbreak current intensification in January 2005 with flow up to 1.2 m s^{-1} during downwelling favorable winds. However, to our knowledge, the current intensification at this location during summer has not been shown in the literature before. The mean easterly flow was around 3 cm s^{-1} (Fig. 9a--c), which is consistent with the observations of \citet{Pickart_2004} for the summertime period along the Alaskan Beaufort shelfbreak. The section along line 600 in the Mackenzie Trough captured an anticyclonic mesoscale eddy ($\sim$50 km diameter) which impacted the patterns of $c_\mathrm{p}(660)$ and chl-\textit{a} fluorescence (Figs. 3e and 10j).~~

on the Mackenzie Shelf (Fig. \ref{fig:VECTOR}d).

Episodes of high along-shelf current speeds (dark green in Fig. \ref{fig:VECTOR}c), such as at the end of the MALINA expedition in late August 2009, but also in November 2008, February, May and July 2009, were generally associated with reductions in salinity and temperature at the CA05 mooring, and perhaps also linked to shelfbreak transport of SPM with downwelling flow.

\subsection{Effects of river runoff and sea ice melt on SPM distributions ~~across~~on the ~~continental margin}~~

This section is focused on discussion of SPM fields (Fig. 10), derived from $c_\mathrm{p}(660)$ profiles using Eq. 2, along with supporting temperature and salinity fields (Fig. 11). We recall that both Eq. 2 and Eq. 3 are valid for $c_\mathrm{p}(660)$ values up to 3.1 m^{-1} (Fig. 5). Thus, this excludes the most mineral-dominated waters on the shelf with SPM over 5.6 g m^{-3} and POC over about 0.5 g m^{-3}. Within the valid range the presented SPM [g m^{-3}] can be converted to POC [g m^{-3}] according to POC $= 0.1279$ SPM$^{0.7307}$, which was derived from the regression analysis of POC vs. SPM data.

\subsubsection{Clear waters}
SPM ranging between 0.04 and 0.06 g m^{-3} was found in offshore waters in each of the three transect lines measured during June-August (Fig. 10). The low SPM values were especially widespread in August 2009 (MALINA) with wedges of very clear water extending far onto the shelf. The corresponding POC ranged from 0.01 to 0.02 g m^{-3}. The extension of clear waters onto the shelf as a wedge between the surface plume and the turbid near bottom layer has been described by \citet{Carmack_etal_1989}. It appears that neither particle settling from the surface plume nor the resuspension of bottom sediments were sufficient in August 2009 to increase these clear-water values of $c_\mathrm{p}(660)$ above those found in deep basin surface waters. The landward extension of the clear-water layer was particularly noticeable on line 600 (Fig. 10j) which corresponds with the Mackenzie Trough (a submarine canyon), the main river channel and the most distinct surface plume feature of the transects. The conditions during MALINA differed from the previous years particularly in terms of sea ice coverage (Fig. 7b). The break-up of the landfast shelf} \label{ice on the shelf occurred late and ice floes were not readily transported away from the shelf due to the northerly and later weak winds. Furthermore, multiyear ice extended further south compared to previous years considered in this study (Fig. 7). As surface salinity remained low for the length of the line 300 (Fig. 11h), the melt water from this ice appears to have influenced the low SPM levels in the shelf waters by increasing the stratification that reduced mixing and by hindering the spread of the particle-rich river plume.

\subsubsection{Effect of ice -melt on SPM distribution}
Comparatively high levels of SPM were found along line 300 (Kugmallit Valley) near the shelf bottom in August 2009 with particularly high values extending across the shelf (Fig. 10h). Such SPM patterns are indicative of downwelling return flow from the shelf after upwelling-inducing wind conditions relaxed. These near-bottom concentrations match those observed during the fall 2007 (Fig. 10f) under high winds (Fig. 8) and brine release from forming ice (Fig. 7) and generally higher salinity shelf waters (Figs. 11b, f). The presence of sea ice and its meltwater on the shelf during August 2009, as seen from the low surface temperatures and salinities at $\sim$70.9° N (Fig. 11h), can explain the containment of the spreading of the plume along line 300 (Fig. 10h). High particle settling rates from a slow moving or stagnant river plume may in turn explain the high near bottom SPM which then could be transported along the shelf bottom with the return flow of the upwelled waters.

A contrasting situation is provided by the conditions observed along line 300 during June-July 2008 (IPY-CFL study) (Figs. 10g and 11g). During the IPY-CFL, ice coverage on the shelf was low (Fig. 6b) and upwelling-inducing winds prevailed throughout June and early July (Fig. 8}

). Consequently, the two compared SPM sections along line 300 differed markedly (Fig. 10g, h). As seen in Fig. 10g, in 2008 the turbid surface river plume spread northward past the shelfbreak. This buoyancy-driven flow was likely enabled by the absence of ice melt water. The near-bottom turbidity was low likely owing to conditions resulting from the notable upwelling event evidenced by the high salinity of the shelf bottom water and the extent of the turbid surface plume (see Fig. 11g).

\subsubsection{River plume variability}
Wind-forcing largely controls the flow direction of the Mackenzie River plume. Due to the size and shape of the Mackenzie Shelf, the most likely direction for the Mackenzie River plume to spread significant distances past the shelfbreak is to the northwest \citep{Doxaran_etal_2012}. During the spring freshet in June 2009, sustained easterly along-shelf winds caused the flaw-lead polynya to widen along the Mackenzie Shelf and a turbid river plume extended northwestward from the landfast ice to the pack ice (Fig. S2). The MALINA sampling occurred during a time of transition from a northwestward plume (during easterly winds) towards a Coriolis-forced right turning plume flowing eastward along the coast. Plumes of both directions are visible in MODIS satellite images for the period of the MALINA expedition \citep{Doxaran_etal_2012, Forest_etal_2013}. By 26 July 2009, the plume was clearly seen extending out past the tip of Cape Bathurst. The sampling along lines 600 and 700 was conducted during the first half of August 2009, following a two-week period of easterly winds (Fig. 8a). By 26 July, the plume was clearly seen extending out past the tip of Cape Bathurst.\ref{fig:VECTOR}a). By mid-August only very weak features remained from the northwestward plume. Notably, both river discharge and ice concentrations on the shelf were reduced by half during the period of one month (Fig. 6).

\ref{fig:RD-SIC}).

Figures 10i, j,\ref{fig:SPM}g, h and 11i, j\ref{fig:TS}g, h show the river plume extending northwest along the Mackenzie Trough (line 600). The Mackenzie River plume occupied an about 15 m thick layer at the sea surface both in July 2004 and August 2009. A sharp decrease in SPM was found immediately below this layer. The surface plumes were accompanied byhad low salinitiessalinity, high meteoric water fractions (Table 1 and, at least for 2009, Fig. \ref{fig:SSURF}a), and high CDOM fluorescence (Fig. 3f)\ref{fig:FLUO}f), at least in 2009, and a high < 1 μm particle volume fraction (Fig. \ref{fig:POC2SPM}c, d), indicating a riverine origin \citep{Matsuoka_etal_2012}.. Interestingly, particle concentrations differed markedly for the two years compared. In 2004, high levels of SPM extended the full length of the transect with values reaching 4 g m^{-3} as far as 70° N. In contrast, in 2009 the SPM values observed in the plume were only about 10 \% of the 2004 values but still distinctly noticeable because the plume overlaid a layer of very clear water. Also, the waters beneath the river plume in 2004 were significantly more turbid compared to 2009, probably due to settling of particles from the plume.

Although the timing of the transect measurements in 2004 and 2009 was a month apart, overall conditions on the shelf were not markedly different. Easterly winds were weak in both cases (Fig. ~~8),~~\ref{fig:VECTOR}), ice coverage on the shelf was 30--40 \%, and the river discharge was $\sim$13,000-14,000 m^3 s^{-1} during both years (Fig. ~~6).~~\ref{fig:RD-SIC}). Moreover, the cross sections along lines 100 (Fig. \ref{fig:SPM}a, c) and 300 ~~(Figs. 10 and 11~~ (Fig. \ref{fig:SPM}d, f) show very similar features and particle concentrations during the two years. The differences between the two situations can be attributed to the seasonal timing. The 2004 transects were measured in early July soon after the break-up of the landfast sea ice cover and the surge of backed-up river waters across the delta and estuary. In contrast, the 2009 measurements were conducted much later in the season after landfast ice break-up. Consequently, in 2004 the surface plume was likely conditioned by a greater initial SPM discharge at the river mouth and by a higher momentum compared to 2009 so that it was capable of keeping more particles in suspension for a longer distance, including larger-sized particles if present. MODIS imagery of sea-surface temperature for 2 July 2004 (Fig. S3 in Supplementary Material) highlights this river plume inertia.

\subsubsection{Surface versus near-bottom cross-shelf SPM distributions}
Comparatively high levels of SPM were found along line 300 (Kugmallit Valley) near the shelf bottom in August 2009 with particularly high values extending across the shelf (Fig. \ref{fig:SPM}f). On line 600 (Fig. \ref{fig:SPM}h), a nepheloid layer with SPM > 0.001 g m^{-3} formed near the 33.1 PSU isohaline at $\sim$100 m depth. It was accompanied by a strong chl-\textit{a} fluorescence signal (Fig. \ref{fig:FLUO}e). Elevated near-bottom and shelfbreak SPM values were also observed during CASES and IPY-CFL (Fig. \ref{fig:SPM}d, g). Such SPM patterns are indicative of downwelling return flow from the shelf after upwelling-inducing wind conditions relaxed. The presence of sea ice and its meltwater on the shelf during August 2009, as seen from the low surface temperatures and salinities at $\sim$70.9° N (Fig. \ref{fig:TS}f) and high meltwater fractions (Fig. \ref{fig:SSURF}a and Table 1), can explain the containment of the spreading of the plume along line 300 (Fig. \ref{fig:SPM}f). High particle settling rates from a slow moving or stagnant river plume may in turn explain the elevated near bottom SPM which then could be transported along the shelf bottom with the return flow of the upwelled waters.

A contrasting situation is provided by the conditions observed along line 300 during June-July 2008 (IPY-CFL study) (Figs. \ref{fig:SPM}e and \ref{fig:TS}e). During the IPY-CFL, ice coverage on the shelf was low (Fig. \ref{fig:RD-SIC}b) and upwelling-inducing winds prevailed throughout June and early July (Fig. \ref{fig:VECTOR}a). Consequently, the two compared SPM sections along line 300 differed markedly (Fig. \ref{fig:SPM}e, f). As seen in Fig. \ref{fig:SPM}e, in 2008 the turbid surface river plume spread northward past the shelfbreak. At the same time, the near-bottom turbidity was low likely owing to conditions resulting from upwelling, evidenced by the high salinity of the shelf bottom water and the extent of the surface plume (see \ref{fig:TS}e). This offshore surface flow was made possible by the absence of sea ice and ice meltwater (buoyancy forcing) and wind-driven Ekman transport.

The low SPM values were especially widespread in August 2009 (MALINA) with wedges of very clear water extending far onto the shelf. FreezeThe conditions encountered during MALINA differed from expeditions in previous years particularly in terms of sea ice coverage (Fig. \ref{fig:RD-SIC}b). The break-up conditions}
Measurements in October 2007 showed a well-mixed upper layer of $\sim$30 m with the highest observed salinities and lowest temperatures on the shelf (Figs. 11b, f). These high salinities were caused by upwelling that was forced by strong easterly winds (Fig. 8; see also \citeauthor{Tremblay_etal_2011}, \citeyear{Tremblay_etal_2011}), but were likely also related to new ice formation that was taking place in shelf waters (Figs. 6 and 7). To illustrate this point, a 30-PSU salinity of a 20-m deep water column would increase by only 0.3 PSU from salt rejected by the formation of 0.3 m thick sea ice (World Meteorological Organization classification for the maximum thickness of the young ice type). Therefore, it is unlikely that sea ice formation alone could account for the observed high salinity.

Similarly to the physical properties, the SPM estimates from $c_\mathrm{p}(660)$ were well-mixed in shelf waters with estimated values reaching 4 g m^{-3} (Fig. 10b, f). Despite the overall higher salinity of the water column in October compared to summer, a halocline was present at 30 m depth (Fig. 11f) beneath which high SPM levels extended towards the shelfbreak. This is an indication of cross-shelf transport of sediment near the bottom. The importance of the release of high-density brine from sea ice formation to particle transport across the Canadian Beaufort shelfbreak was discussed by Forest et al. (2007).

In October 2007 a 40--50 m thick layer of the upper water column with SPM in the range 0.40--0.55 g m^{-3} extended the full length of the still ice-free line 100 (Fig. 10b). These are the highest values seen for surface waters within the Amundsen Gulf in our study. The source of these particles in the Amundsen Gulf is difficult to trace. Winds were sufficiently strong to cause resuspension of SPM on the shelf and other nearby coastal areas. However, the wind direction was easterly (Fig. 8) such that surface waters on the Mackenzie shelf and in Amundsen Gulf flowed mainly northwest, i.e., away from Amundsen Gulf (measured with acoustic current profiler on mooring CA05; data not shown). In freezing waters the $c_\mathrm{p}(660)$ signal could have been affected by the formation of frazil ice (small ice crystal particles). However, in this case this was not likely to happen because the surface layer along line 100 remained 0.5--1.5 $^{\circ}$C above the freezing point even though ice was forming on the shelf and along the coast (Fig. 7). of the landfast ice on the shelf occurred relatively late and ice floes were not readily transported away from the shelf due to the northerly and, then later, weak winds (Fig. \ref{fig:VECTOR}a). Furthermore, multiyear ice extended further south compared to the two other years considered in this study (Fig. \ref{fig:CIS}). At around 70.5° N on line 300, which coincides with northward extent of the river plume and rapid decrease in water column SPM levels (Fig. \ref{fig:SPM}f), the surface salinity decreased below 27 PSU and temperature was <5 $^{\circ}$C (Fig. \ref{fig:TS}f) with over >70 \% f_{SIM} fraction of the freshwater (Fig. \ref{fig:SSURF}a). As sea surface salinity remained low for the length of line 300 (Fig. \ref{fig:SPM}f), we argue that the meltwater from this ice influenced the low SPM levels in the shelf waters by increasing the stratification, reducing vertical mixing, and hindering the northward spread of the particle-rich river plume.

Another contrasting situation is seen in the Amundsen Gulf along line 100 (Fig. \ref{fig:SPM}a--c) where differences in conditions between the years can be explained by the presence or absence of sea ice, and the history of wind forcing as it relates to SPM transport from the shelf. Whereas ice free and comparatively clear surface waters were present in 2008 (Fig. \ref{fig:SPM}b), turbid (i.e., high $c_\mathrm{p}(660)$ and SPM) surface waters extended across Amundsen Gulf in 2004 and 2009 (Figs. \ref{fig:SPM}a, c), and the surface was furthermore partially ice covered in June 2004 (Fig. \ref{fig:CIS}a). The temperature and salinity fields, however, showed only modest differences between conditions in 2004, 2008, and 2009 (Fig. \ref{fig:TS}a--c). This suggests that the turbid surface waters in 2004 and 2009 were caused by the presence of shelf waters with particles originating from the Mackenzie River and/or via resuspension of shelf sediments. This is corroborated by the observed high meteoric water fractions in 2004 and 2009 (Table 1), and the high fraction of < 1 μm particles in the surface waters in 2009 (Fig. \ref{fig:POC2SPM}d). The equally fresh but clear surface layer in July 2008, after a long period of easterly winds (Fig. \ref{fig:VECTOR}a) and consequent westward circulation on the shelf \citep{Mol_etal_2018}, was however associated with sea ice meltwater with relatively low concentration of particles. The observations that f_{MW} at stations 110 and 140 in July 2008 (IPY-CFL) were of similar magnitude to those observed during CASES and MALINA may be an indication of the importance of resuspension in the supply of SPM to surface water.

\citet{Tremblay_etal_2011} ~~reported on the upwelling of nutrients to reach the highest concentration of nitrate (16.8 ${\mu}$M) ever observed in the region on the shelf northwest of Cape Bathurst, which caused an increase in primary production. These high nitrate values did not extend far past the shelfbreak and remained low across Amundsen Gulf. Although, chl-\textit{a} fluorescence data for the surface waters indicated the elevated concentrations of phytoplankton \citep{Tremblay_etal_2011}, it is not possible to conclude that phytoplankton concentrations were sufficient to explain the high $c_\mathrm{p}(660)$.~~

~~\subsubsection{Implications to primary production}~~
~~The high $c_\mathrm{p}(660)$ values near the shelf seafloor in August 2009 were accompanied by a strong chl-\textit{a} fluorescence signal that extended from the shelf into the Canada Basin as a subsurface chl-\textit{a} maximum (SCM) layer (Fig. 3).~~discussed the conditions in 2008, as well as nutrient dynamics, leading up to the high primary productivity observed in the Amundsen Gulf during the summer of 2008. The productivity of the SCM is generally proportional to the concentration of chl-\textit{a} and limited by light and nutrient availability \citep{Martin_etal_2010}. ~~SPM distribution may be of importance for the~~

formation and maintenance of the SCM as illustrated by the two following examples from our observations.

First, the patterns of $c_\mathrm{p}(660)$ and chl-\textit{a} fluorescence suggest that biological production on the shelf bottom\citet{Tremblay_etal_2011} proposed that the unusually early clearing of sea ice in 2008 was enhanced by the upwelled nutrient-rich waters and, at the time of our measurements, biogenic material was being transported seaward in an intermediate nepheloid layer across the shelfbreak at 50--70 m depth \citep[Figs. 3 and 10;][]{Tremblay_etal_2011}. The shelf circulation at play makes it conceivable that the transport of biogenic material produced on the shelf, including resuspension of settled particles originating from an earlier bloom (e.g. ice algae), could potentially influence the formation and maintenance of the SCM in the off-shelf region. Thus, the study of shelf-basin exchange processes leading to the subsurface transport of nutrients and biogenic material may be of biological importance to improve the understanding of pelagic-benthic coupling in the region.

Second, the key factor in increasing the subsurface light availability in the Beaufort Sea and Amundsen Gulf is largely governed by the seasonal cycle and the presence of sea ice. \citet{Tremblay_etal_2011} discussed these conditions, as well as nutrient dynamics, leading up to the high biological productivity observed in the Amundsen Gulf during summer 2008. Our observations indicate that the SCM may also be influenced byand primary productivity. However, the influence of the optical water clarity of the surface water layer. was not considered. For example, Figs. \ref{fig:SPM}a--c reveal that in July 2008 (Fig. 10c) displayed, beneath the low turbidity surface layer, a higher SPM in the SCM centered at the 31.5 PSU isohaline (~50 m depth) was observed compared to June 2004 and August 2009 (Fig. 10a, d). This indicates that higher levels of solar radiation reached the SCM such that phytoplankton growth could reach a higher biomass.

Whereas ice free and comparatively clearwhen surface waters were present in 2008 (Fig. 10c), turbid (i.e., high $c_\mathrm{p}(660)$ and SPM) surface water layers extended across Amundsen Gulf in 2004, 2007 and 2009 (Fig. 10a, b, d), and the surface was partially ice covered in June 2004 (Fig. 7a). Time of year and consequent differences in river discharge and ice conditions are naturally expected to influence the size of the Mackenzie River plume. The temperature and salinity fields, however, show only modest differences between conditions in 2004, 2008 and 2009 (Fig. 11a, c, d). This suggests that the fresh and turbid surface layers present in 2009 were caused by the spreading of fresh were more turbid. Thus, we suggest that the cross-shelf waters affected by the Mackenzie River, while the equally fresh but clear layer in 2008 was associated with sea ice melt water. The difference in conditions between the years may thus be explained by the presence or absence of sea ice, and generally by the history of wind forcing, and how these two factors affect the spreading of the river plume.

\subsubsection{Nepheloid layers on the slope and beyond}
Figure 10 reveals a ubiquitous presence of numerous subsurface nepheloid layers extending from the Beaufort Sea continental slope. These nepheloid

layers are produced primarily by resuspension of bottom sediments settled onto the shelf or slope, and provide evidence for the transport of suspended particles and water away from the shelf. It is important to differentiate these layers from the mainly locally formed subsurface chl-\textit{a} maximum (SCM) layer that is commonly present in the Canadian Beaufort Sea \citep{Martin_etal_2010, Tremblay_etal_2011}. As the SCM seems to intersect with the shelf bottom (Fig. 3), the presence of relatively high chl-\textit{a} concentrations within subsurface nepheloid layers may however conceal the presence of minerogenic particles at the same depth.

On line 600, two subsurface nepheloid layers (in addition to the surface river plume) extending from the shelf at depths of 100--130 m and 200--250 m, were observed in 2004 and 2009 (Fig. 10i, j). These two layers appeared to form near where the 33.1 PSU isohalines intersected the shelf seafloor and immediately above and below a slightly less sloping section of the Mackenzie Trough bottom (Fig. 11i, j). However, only the upper layer was accompanied by relatively high chl-\textit{a} fluorescence (Fig. 3c). The depths of 100 m and greater are beneath the euphotic layer rendering primary production negligible. Thus, these chl-\textit{a} containing particles likely represent transported particles that originated in shallower shelf waters.

Numerous intermediate nepheloid layers (INLs) are seen in the upper 500 m of the water column throughout the Amundsen Gulf (Figs. 10a-d) and extending into Canada Basin (Figs. 10e-j). The cast-to-cast variability in the depth location of these INLs is large (Fig. 12) making it difficult to trace the shelf/slope origin of the INLs in this dynamic system. Generally, the SPM of INLs in offshore waters was an order of magnitude smaller than in the benthic nepheloid layer (BNL) on shelf and particle concentrations decreased with distance from the shelf.

Beneath 500 m depth, the vertical profiles of SPM still showed numerous inversions (Fig. 12). Generally, however, the particle concentration at specific depths decreased as bottom depth increased as it also relates to the distance from the shelfbreak. This decrease is approximately exponential with distance from the shelfbreak. In waters less than 3000 m deep located on the continental slope and rise, the SPM began to increase from about the mid depth of the water column which had the clearest waters. The thickness of these BNLs ranged from $\sim$200 m (station 340) to over 1000 m (Fig. 12). Past the 3000 m bottom depth, BNLs were essentially absent with the clearest waters found close to the bottom as may also be the case for the Canada Basin abyssal plain \citep{Hunkins_etal_1969}. Near-bottom SPM values based on $c_\mathrm{p}(660)$ were $\sim$2$\times$10^{-3} g m-3 at the station CB-27, and decreased to $\sim$1$\times$10^{-3} g m^{-3} at 3500 m at CB-21 (74.0042° N, 139.8699° W, i.e., 113 km north of CB-27) on 9 October. After detaching from the BNL on the slope, INLs were advected along isopycnal surfaces. With distance, INLs became thinner with lower SPM owing to lateral spreading to cover larger areas, mixing at layer boundaries, and settling of particles.

It is thus of interest to investigate in more detail two obvious INLs seen in Fig. 12a. Station 530 showed an INL at ~1200 m depth with SPM of

$\sim$0.030 g m^{-3}. SPM in the overlying water was 0.021 g m^{-3}. It is clear that the INL must have been detached and advected from the bottom layers on the slope (perhaps near to adjacent stations 550 or 440 with a near-bottom SPM of ~0.050 g m^{-3} at 1050--1100 m). Interestingly, station CB-27 located at 73° N showed a similar INL with the SPM maximum of 6.9$\times$10^{-3} g m^{-3} at 1170 m where the potential density anomaly, σ_θ, was 28.032 kg m^{-3}. However, neither CB-23 nor CB-31 located to the east had INLs at that isopycnal. Over the distance of 240 km separating the stations 530 and CB-27, the SPM decreased by about 0.023 g m^{-3}, which corresponds to about 1$\times$10^{-4} g m^{-3} km^{-1}.

A notable INL at stations CB-23, CB-27, and CB-21 was spreading in the layer immediately below the isopycnal surface where the potential density anomaly σ_θ reached 28.096 kg m^{-3} or the salinity reached 34.956 (Fig. 12). The depth where this occurred varied between the stations. Beneath this interface the potential temperature was uniform with depth, thereby marking a transition to the adiabatic Canada Basin bottom water layer \citep[e.g.,][]{Timmermans_etal_2003}. Assuming that the particles in the INL were from the bottom layer of CB-31 (~1920 m depth with σ_θ = 28.093 kg m^{-3}), then the transport of particles from the bottom of station CB-31 to the INL at station CB-23 requires a 560 m increase in depth over a 100 km distance, which equals a sinking rate of 5.6 m km^{-1}. Such transport of particles crosses isopycnal surfaces, suggesting the predominant role of particle settling in addition to advective transport. Furthermore, following the BNL to station 330 from CB-31, the BNL depth increased by 900 m over the distance of 88 km such that the descent rate was 10.2 m km^{-1}. This decrease in the rate of sinking with distance from the slope may illustrate the process by which the larger/heavier particles sink faster, or are broken down by biological processes, and are gradually removed from the nepheloid layer until only smaller particles remain in suspension. Some smaller sized particlestransport of SPM in surface plumes may additionally have detached from the BNL forming the numerous INLs as observed, for example, at station CB-31 at depths between 1100 and 1900 m.

The maximum SPM within the INL at station CB-23 was 0.0126 g m^{-3} at 2470 m depth. At CB-27 the maximum was 8.2$\times$10^{-3} g m^{-3} at 2600 m (Fig. 12). The SPM levels above the INLs (with σ_θ = 28.095) were 0.010 and 0.027 g m^{-3}, respectively. Given that the INL depth increased by 130 m over the 128 km distance that separated the two stations, the INL descent rate was about 1 m km^{-3}. A thinner (50 m thick) and weaker INL with a maximum SPM of 3.2$\times$10^{-3} g m^{-3} at 2656 m was observed at CB-21 (Fig. 12d). The INL descent rate over 113 km distance between CB-27 and CB-21 was about 0.5 m km^{-1}. Because the maximum SPM at these INLs occurred at the same σ_θ, this descent of the INLs was determined by the water mass structure, however, the decrease of SPM within the maxima reflect processes such as spreading, settling, aggregation, scavenging, and mixing of particulate matter. The SPM in the INL was found to decrease linearly with the square root of distance from the shelf while background SPM decreased exponentially with distance. A correlation analysis based on data from station 330 and the four stations from CB-31 through CB-21,

~~showed a linear decrease in SPM at the INL maxima as a function of the depth location of the maximum, z_{peak} with the best fit equation SPM [g m^{-3}] = $-$3.88$\times$10^{-5} z_{peak} + 0.107 (r^2=0.99). Interestingly, both the depth and the magnitude of the SPM maximum were found to increase or decrease linearly with the square root of the distance from the shelfbreak with slopes of 92.3 m km$^{-1/2}$ (r^2=0.97) and $-$3.6$\times$10^{-3} g m^{-3} km$^{-1/2}$ (r^2=0.97), respectively.~~

influence primary productivity in Amundsen Gulf by reducing light penetration.

\conclusions~~[Summary and Conclusions]~~

The data collected in the southeastern Beaufort Sea during the MALINA ~~field campaign~~ in August 2009 enabled the development of relationships for estimating SPM and POC from measurements of optical beam attenuation coefficient. These relationships provided, in turn, a means for obtaining a comprehensive view of particle concentration fields ~~and characteristics~~ covering the full expanse of the Canadian Beaufort Sea continental margin on the basis of optical data collected during several expeditions in this region. Accompanying water sampling enabled us to conduct a detailed assessment of oceanographic conditions and particle characteristics, including freshwater sources, particle size and composition. Our analysis revealed temporal and spatial variations in particle concentration and dynamics which could be attributed to (i) discharge of the Mackenzie River, (ii) ice coverage and ~~thermodynamics~~meltwater, and (iii) wind forcing. These three factors ~~affect the advection of~~control the ~~river plume and the overall~~ estuarine-like two-layer circulation on the shelf~~. As a result there~~ during summer, and are ~~three modes of particle~~reflected in cross-shelf SPM patterns that suggest transport ~~on the shelf; (1)~~occurring mainly within a buoyant surface ~~plume, (2) resuspended particles within a benthic nepheloid layer (BNL), and (3) within a mixed water column during high wind speeds (> 12 m s^{-1}).~~river plume and the bottom boundary layer. SPM on the shelf ~~exceeds~~exceeded 1 g m^{-3} in each of these cases. A clear water layer was ~~typically~~also found ~~in~~at mid-~~layers~~depths on the outer shelf. Similar features were ~~also~~ noted by \citet{Carmack_etal_1989}.

The wind-driven shelfbreak upwelling and downwelling signals were clearly present in the CA05 mooring record for the base of the Pacific Water layer (Fig. \ref{fig:VECTOR}b) on the continental slope at the mouth of Amundsen Gulf (Fig. \ref{fig:MAP}) at a depth corresponding to an eastward flowing shelfbreak jet (Fig. \ref{fig:GEOSTROPHIC}). At 178 m depth, the current was seen to follow isobaths during quiescent and downwelling favorable conditions, but switched to move cross shelf during upwelling favorable winds (Fig. \ref{fig:VECTOR}a, b). Interestingly, there appeared to be two very distinct modes of flow at this depth and location along the slope. In 2009, the salinity at 178 m reached 34.5 PSU during the upwelling events (Fig. \ref{fig:VECTOR}d), which corresponds to an effective depth of about 300 m \citep{Carmack_Kulikov_1998}. However, in all cross-shelf transects shown in Fig. \ref{fig:TS}, salinities of at least 32.3 PSU were found on the shelf at 60--80 m depth. This salinity corresponded to the transition between Pacific

Summer Water and Winter Water, which is typically found at 100 m depth in the Canada Basin \citep[e.g.,][]{Carmack etal 1989}. The salinity on the shelf was higher than in corresponding Canada Basin waters at all times and all observed sections.

~~We found that the buoyant sea ice melt water~~Thus, this modest 20--40 m of (depth equivalent) upwelling onto the shelf may represent a steady state condition linked to the generally easterly wind and anticyclonic circulation of the Beaufort Gyre.

Freshwater inputs from the Mackenzie River and the melting of sea ice resulted in surface waters being a varying mixture f_{MW}, f_{SIM} and f_{PSW}, where PSW refers to Pacific Summer Water with a core salinity of 31.5 PSU. We found that the buoyant sea ice meltwater competed for space with the river plume, and in contrast contained little particulate matter (and CDOM; Fig. ~~3),~~\ref{fig:FLUO}), which had a significant effect on SPM distributions within the surface layer. When ice ~~melt water~~meltwater was present on the shelf during years with high ice coverage~~ (Fig. 11),~~, it appeared to restrict the expansion of the surface river plume, and cross-shelfbreak transport of particles was consequently found to occur mainly along the shelf bottom in a ~~BNL~~benthic nepheloid layer (Fig. ~~10).~~\ref{fig:SPM}). This was a consequence of two factors: (i) the reduction in plume buoyancy driving force by the sea ice ~~melt water~~meltwater layer such that more particles carried by a slower moving or stagnant plume were settled to the bottom, and (ii) weak or westerly winds that allowed sea ice and ~~melt water~~meltwater to remain on the shelf and ~~caused~~to initiate downwelling return flow (after relaxation of wind-induced upwelling) that could transport particles in the ~~BNL.~~

~~The wind-driven upwelling signal was clearly present in the current meter record at the base of the Pacific Water layer at 180--200 m for mooring CA05 (Fig. 8b) located on the continental slope (Fig. 1) at a depth corresponded to an eastward flowing shelfbreak jet (Fig. 9). At the 180-200 m depth, the currents were seen to follow isobaths during quiescent conditions, but then switched to moving cross shelf during strong upwelling favorable winds (Fig. 8a). Interestingly, there appeared to be two very distinct modes of flow at this depth along the slope. In 2009, the salinity at 178 m reached 34.5 during the upwelling events (Fig. 8e~~bottom boundary layer towards the shelfbreak.

Particle characteristics in surface waters differed considerably depending on the relative contributions of river runoff and sea ice meltwater. Compared to sea ice meltwater, river runoff carried significantly higher SPM loads (Fig. \ref{fig:SPM}), had a particle size distribution with a higher fraction of submicron particles, a smaller POC to SPM ratio (i.e., more minerogenic particles), and a high CDOM content (Figs. \ref{fig:FLUO}--\ref{fig:POC2SPM}). These differences have implications on the optical properties of the water, and consequently affect the propagation of sunlight and primary productivity during the open water season.

~~), which corresponds to an effective depth of about 300 m \citep{Carmack_Kulikov_1998}. However, in all cross-shelf transects shown in Fig. 11, salinities of at least 32.3 PSU were found on the shelf at~~

~~60--80 m depth. This salinity corresponded to the transition between Pacific Summer Water and Winter Water, which is typically found at 100 m depth in the Canada Basin \citep[e.g.,][]{Carmack_etal_1989}. The salinity on the shelf was higher than in corresponding Canada Basin waters at all times and all observed sections. Thus, a modest 20--40 m of (depth equivalent) upwelling onto the shelf may represent a steady state condition linked to the generally easterly wind and anticyclonic circulation of the Beaufort Gyre.~~

~~The presence of the SCM layer \citep{Martin_etal_2010} at the base of the Pacific Summer Water mass was a consistent feature in the southern Beaufort Sea but was also observed to intersect with the BNL on the shelf (Fig. 3). Apart from the SCM, the depth locations and particle concentrations of INLs were found to be highly variable and numerous in top 500 m of the water column, highlighting the complex conditions responsible for their formation. The high SPM seen on the shelf did not extend far past the shelfbreak except in a westward flowing river plume (Fig. 10; see also Fig. S2 in Supplementary Material). Thus, subsurface sediment transport beyond the shelfbreak must occur in a near bottom BNL which detaches into INLs at specific depths as determined by physical processes and particle characteristics. Further research is required to explore this observation in detail. Past the shelfbreak, the SPM at specific depths generally decreased with distance from the shelfbreak and with increasing depth. The $c_\mathrm{p}(660)$ profiles in Canada Basin waters agree with the two types of profiles described in \citet{Hunkins_etal_1969}, first, in waters with bottom depths less than about 3000 m the SPM had minimum values roughly at mid-depths of the water column and then increased towards the bottom forming a c-shaped profile, and second, in waters exceeding the 3000 m depth the SPM reached minimum values near the bottom. The deepest INL (below which no INLs were seen) extending to the Canada Basin abyssal plain was observed at the 2500--2600 m depth at the top of the adiabatic Canada Basin bottom water layer \citep{Timmermans_etal_2003}.~~

As the Arctic continues to warm, the open water season is expected to become increasingly longer and the extent of multiyear ice further decline \citep{Stroeve_etal_2014}. The reduction in ice coverage in the Beaufort Sea implies an increase in SPM dynamics on the continental margin due to the associated changes in wind forcing and river discharge \citep{Carmack_etal_2006}. Greater wind and wave forcing on open waters is expected to increase particle concentrations on the shelf. However, the presence of both clear intermediate waters and highly turbid bottom waters observed on the shelf in this study highlighted interesting linkages to the effect of sea ice on river water and particle transport on the shelf, which need further study. The processes that operate within subsurface layers and ice-covered waters cannot be deciphered through satellite remote sensing, so their quantification requires in-situ monitoring. Optical beam transmission is a simple yet efficient tool for mapping SPM distributions. The relationship between SPM and $c_\mathrm{p}(660)$ developed in this study can be applied to past and future transmissometer observations to monitor changes ~~to~~in SPM. Vertical measurements reaching all the way to the seafloor would be very beneficial when attempting to determine lateral SPM transport. This is typically not done due to the risk to the instruments. Furthermore, ongoing research that considers current speeds together with particle size distributions are needed in order to shed more light on particle transport and settling processes across the Beaufort Sea continental shelf, and slope and rise, which are experiencing considerable change in response to river discharge, sea ice coverage, and wind forcing. The results from this study can help evaluate numerical models which may be used to investigate sensitivities of SPM dynamics associated with oceanographic and forcing conditions on the Mackenzie Shelf.

```
%% The following commands are for the statements about the availability of data sets and/or software code corresponding to the manuscript.
%% It is strongly recommended to make use of these sections in case data sets and/or software code have been part of your research the article is based on.

% \codeavailability{TEXT} %% use this section when having only software code available


\dataavailability{All data used in this study are available in the following online data bases: Polar Data Catalogue, Water Survey of Canada (Environment Canada), Canadian Ice Service (Environment Canada), National Centers for Environmental Prediction (NCEP), and the French national IMBER/SOLAS data base.} %% use this section when having only data sets available


% \codedataavailability{TEXT} %% use this section when having data sets and software code available


% \sampleavailability{TEXT} %% use this section when having geoscientific samples available



%\appendix
%\section{}    %% Appendix A
%
%\subsection{}     %% Appendix A1, A2, etc.
%
%
%\noappendix       %% use this to mark the end of the appendix section
%
%%% Regarding figures and tables in appendices, the following two options are possible depending on your general handling of figures and tables in the manuscript environment:
%
%%% Option 1: If you sorted all figures and tables into the sections of the text, please also sort the appendix figures and appendix tables into the respective appendix sections.
%%% They will be correctly named automatically.
%
```

%%% Option 2: If you put all figures after the reference list, please insert appendix tables and figures after the normal tables and figures.
%%% To rename them correctly to A1, A2, etc., please add the following commands in front of them:
%
%\appendixfigures %% needs to be added in front of appendix figures
%
%\appendixtables   %% needs to be added in front of appendix tables
%
%%% Please add \clearpage between each table and/or figure. Further guidelines on figures and tables can be found below.

\authorcontribution{JKE drafted the manuscript, ~~analyzed~~analysed the data and prepared the figures. JKE and DD collected and analysed the SPM and POC data, while RR conducted the particle size distribution sampling. BL conducted all $\delta^{18}O$ sampling. All coauthors contributed to writing the manuscript.} %% optional section

\competinginterests{The authors declare that they have no conflict of interest.} %% this section is mandatory even if you declare that no competing interests are present

% \disclaimer{TEXT} %% optional section

\begin{acknowledgements}
This study was conducted as part of the MALINA Scientific Program funded by ANR (Agence Nationale de la Recherche), INSU-CNRS (Institut National des Sciences de l‚ÄôUnivers ‚Äì Centre National de la Recherche Scientifique), CNES (Centre National d‚ÄôEtudes Spatiales), ESA (European Space Agency), and the ArcticNet Canadian Network of Centres of Excellence. Additional funding for JKE, RAR, and DS was provided by the US National Aeronautics and Space Administration (Grant NNX07AR20G). JKE is funded by the Natural Sciences and Engineering Research Council of Canada (NSERC) Discovery Grant program. We thank the National Aeronautics and Space Administration (NASA), National Centers for Environmental Prediction (NCEP), and Environment Canada for providing free access to data. We thank all participants on the CASES, ArcticNet, IPY-CFL and MALINA cruises for their help, and in particular all of the crew members on \textit{CCGS Amundsen}.
\end{acknowledgements}

%% REFERENCES

\begin{thebibliography}{}

\bibitem[Asplin et al.(2012)]{Asplin_etal_2012}
Asplin, M. G., Galley, R., Barber, D. G., and Prinsenberg, S.: Fracture of summer perennial sea ice by ocean swell as a result of Arctic storms, J. Geophys. Res., 117, C06025, doi:10.1029/2011JC007221, 2012.

\bibitem[Babin et al.(2003a)]{Babin_etal_2003a}
Babin, M., Stramski, D., Ferrari, G. M., Claustre, H., Bricaud, A., Obolensky, G., and Hoepffner, N.: Variations in the light absorption coefficients of phytoplankton, nonalgal particles, and dissolved organic matter in coastal waters around Europe, J. Geophys. Res., 108 (C7), 3211, doi:10.1029/2001JC000882, 2003a.

\bibitem[Babin et al.(2003b)]{Babin_etal_2003b}
Babin, M., Morel, A., Fournier-Sicre, V., Fell, F., and Stramski, D.: Light scattering properties of marine particles in coastal and open ocean waters as related to the particle mass concentration, Limnol. Oceanogr., 48(2), 843--859, 2003b.

\bibitem[Barber et al.(2010)]{Barber_etal_2010}
Barber, D. G., Asplin, M. G., Gratton, Y., Lukovich, J. V., Galley, R. J., Raddatz, R. L., and Leitch, D.: The International polar year (IPY) circumpolar flaw lead (CFL) system study: Overview and the physical system, Atmos.-Ocean, 48(4), 225--243, doi:10.3137/OC317.2010, 2010.

\bibitem[B\'elanger et al.(2013)]{Belanger_etal_2013}
B\'elanger, S., Cizmeli, S. A., Ehn, J., Matsuoka, A., Doxaran, D., Hooker, S., and Babin, M.: Light absorption and partitioning in Arctic Ocean surface waters: impact of multiyear ice melting, Biogeosciences, 10, 6433--6452, doi:10.5194/bg-10-6433-2013, 2013.

\bibitem[Bishop(1986)]{Bishop_1986}
Bishop, J. K. B.: The correction and suspended mass calibration of Sea Tech transmissometer data, Deep-Sea Res., 33, 121--134, 1986.

\bibitem[Bishop(1999)]{Bishop_1999}
Bishop, J. K. B: Transmissometer measurement of POC, Deep-Sea Res., I 46, 353--369, 1999.

\bibitem[Boss et al.(2009)]{Boss_etal_2009}
Boss, E., Slade, W., and Hill, P.: Effect of particulate aggregation in aquatic environments on the beam attenuation and its utility as a proxy for particulate mass, Opt. Express, 17(11), 9408--9420, doi:10.1364/OE.17.009408, 2009.

\bibitem[Bricaud et al.(1981)]{Bricaud_etal_1981}
Bricaud, A., Morel, A., and Prieur, L.: Absorption by dissolved organic matter of the sea (yellow substance) in the UV and visible domains, Limnol. Oceanogr., 26, 43--53, doi:10.4319/lo.1981.26.1.0043, 1981.

\bibitem[Bunt et al.(1999)]{Bunt_etal_1999}
Bunt, J. A. C., Larcombe, P., and Jago, C. F.: Quantifying the response of optical backscatter devices and transmissometers to variations in suspended particulate matter, Cont. Shelf Res., 19(9), 1199--1220, doi:10.1016/S0278-4343(99)00018-7, 1999.

\bibitem[Carmack et al.(1989)]{Carmack_etal_1989}

Carmack, E. C., Macdonald, R. W., and Papadakis, J. E.: Water mass structure and boundaries in the Mackenzie shelf estuary, J. Geophys. Res., 94, 18043--18055, 1989.

\bibitem[Carmack et al.(2006)]{Carmack_etal_2006}
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, doi:10.1016/j.pocean.2006.10.005, 2006.

\bibitem[Carmack and Chapman(2003)]{Carmack_Chapman_2003}
Carmack, E., and Chapman, D. C.: Wind-driven shelf/basin exchange on an Arctic shelf: The joint roles of ice cover extent and shelf-break bathymetry, Geophys. Res. Lett., 30(14), 1778, doi:10.1029/2003GL017526, 2003.

\bibitem[Carmack and Kulikov(1998)]{Carmack_Kulikov_1998}
Carmack, E. C., and Kulikov, E. A.: Wind-forced upwelling and internal Kelvin wave generation in Mackenzie Canyon, Beaufort Sea, J. Geophys. Res., 103, 18447--18458, 1998.

\bibitem[Carmack and Macdonald(2002)]{Carmack_Macdonald_2002}
Carmack, E. C., and Macdonald, R. W.: Oceanography of the Canadian shelf of the Beaufort Sea: A setting for marine life, Arctic, 55 (Supp. 1), 29--45, 2002.

\bibitem[Cetini\'c et al.(2012)]{Cetinic_etal_2012}
Cetini\'c, I., Perry, M. J., Briggs, N. T., Kallin, E., D‚ÄôAsaro, E. A., and Lee, C. M.: Particulate organic carbon and inherent optical properties during 2008 North Atlantic Bloom Experiment, J. Geophys. Res., 117, C06028, doi:10.1029/2011JC007771, 2012.

\bibitem[Doxaran et al.(2012)]{Doxaran_etal_2012}
Doxaran, D., Ehn, J., B\'{e}langer, S., Matsuoka, A., Hooker S., and Babin, M.: Optical characterisation of suspended particles in the Mackenzie River plume (Canadian Arctic Ocean) and implications for ocean colour remote sensing, Biogeosciences, 9, 3213--3229, doi:10.5194/bg-9-3213-2012, 2012.

\bibitem[Dmitrenko et al.(2016)]{Dmitrenko_etal_2016}
Dmitrenko, I. A., Kirillov, S. A., Forest, A., Gratton, Y., Volkov, D. L., Williams, W. J., Lukovich, J. V., Belanger, C., and Barber, D. G.: Shelfbreak current over the Canadian Beaufort Sea continental slope: Wind-driven events in January 2005, J. Geophys. Res., 121, doi:10.1002/2015JC011514, 2016.

\bibitem[Forest et al.(2007)]{Forest_etal_2007}
Forest, A., Sampei, M., Hattori, H., Makabe, R., Sasaki, H., Fukuchi, M., Wassmann, P., and Fortier, L.: Particulate organic carbon fluxes on the slope of the Mackenzie Shelf (Beaufort Sea): Physical and biological forcing of shelf-basin exchanges, J. Mar. Sys., 68, 39--54, doi:10.1016/j.jmarsys.2006.10.008, 2007.

\bibitem[Forest et al.(2010)]{Forest_etal_2010}

Forest, A., B\'elanger, S., Sampei, M., Sasaki, H., Lalande, C., and Fortier, L.: Three-year assessment of particulate organic carbon fluxes in Amundsen Gulf (Beaufort Sea): Satellite observations and sediment trap measurements, Deep-Sea Res. I, 57, 125--142, doi:10.1016/j.dsr.2009.10.002, 2010.

\bibitem[Forest et al.(2013)]{Forest_etal_2013}
Forest A., Babin, M., Stemmann, L., Picheral, M., Sampei, M., Fortier, L., Gratton, Y., B\'elanger, S., Devred, E., Sahlin, J., Doxaran, D., Joux, F., Ortega-Retuerta, E., Jeffrey, W. H., Mart\'in, J., Gasser, B., Miquel, J. C.: Ecosystem function and particle flux dynamics across the Mackenzie Shelf (Beaufort Sea, Arctic Ocean): an integrative analysis of spatial variability and biophysical forcings, Biogeosciences, 10, 2833--2866, 2013.

\bibitem[Forest et al.(2015)]{Forest_etal_2015}
Forest, A., Osborne, P. D., Fortier, L., Sampei, M., and Lowings, M. G.: Physical forcings and intense shelf‚Äìslope fluxes of particulate matter in the halocline waters of the Canadian Beaufort Sea during winter, Cont. Shelf Res., 101, 1--21, doi:10.1016/j.csr.2015.03.009, 2015.

\bibitem[Galley et al.(2008)]{Galley_etal_2008}
Galley, R. J., Key, E., Barber, D. G., Hwang, B. J., and Ehn, J. K.: Spatial and temporal variability of sea ice in the southern Beaufort Sea and Amundsen Gulf: 1980--2004, J. Geophys. Res., 113, C05S95, doi:10.1029/2007JC004553, 2008.

\bibitem[Gardner et al.(2006)]{Gardner_etal_2006}
Gardner, W. D., Mishonov, A. V., and Richardson, M. J.: Global POC concentrations from in-situ and satellite data, Deep-Sea Res. II, 53, 718--740, doi:10.1016/j.dsr2.2006.01.029, 2006.

~~\bibitem[Guay and Bishop(2002)]{Guay_Bishop_2002}
Guay, C. K. H., and Bishop, J. K. B.: A rapid birefringence method for measuring suspended CaCO3 concentrations in seawater, Deep-Sea Res. I, 49, 197--210, 2002.~~

\bibitem[Hill et al.(2011)]{Hill_etal_2011}
Hill, P. S.,Boss, E., Newgard, J. P., Law, B. A., and Milligan, T. G.: Observations of the sensitivity of beam attenuation to particle size in a coastal bottom boundary layer, J. Geophys. Res., 116, C02023, doi:10.1029/2010JC006539, 2011.

\bibitem[Honjo et al.(2010)]{Honjo_etal_2010}
Honjo, S., Krishfield, R. A., Eglinton, T. I., Manganini, S. J., Kemp, J. N., Doherty, K., Hwang, J., McKee, T. K., and Takizawa, T.: Biological pump processes in the cryopelagic and hemipelagic Arctic Ocean: Canada Basin and Chukchi Rise, Prog. Oceanogr., 85, 137--170, doi:10.1016/j.pocean.2010.02.009, 2010.

\bibitem[Hunkins et al.(1969)]{Hunkins_etal_1969}
Hunkins, K., Thorndike, E. M., and Mathieu, G.: Nepheloid layers in the Arctic Ocean, J. Geophys. Res., 74(28), 6995--7008, 1969.

\bibitem[Ingram et al.(2008)]{Ingram_etal_2008}
Ingram, R. G., Williams, W. J., van Hardenberg, B., Dawe, J. t., and Carmack, E. C.: Seasonal circulation over the Canadian Beaufort Shelf, in: On Thin Ice: a synthesis of the Canadian Arctic Shelf Exchange Study (CASES), Aboriginal Issues Press, Winnipeg, Manitoba, Canada, 14--35, 2008.

\bibitem[Jackson et al.(2010)]{Jackson_etal_2010}
Jackson, J. M., Allen, S. E., Carmack, E. C., and McLaughlin, F. A.: Suspended particles in the Canada Basin from optical and bottle data, 2003,Äì2008, Ocean Sci., 6, 799--813, doi:10.5194/os-6-799-2010, 2010.

\bibitem[Jackson et al.(2015)]{Jackson_etal_2015}
Jackson, J. M., Melling, H., Lukovich, J. V., Fissel, D., and Barber, D. G.: Formation of winter water on the Canadian Beaufort shelf: New insight from observations during 2009--2011, J. Geophys. Res., 120, 4090--4107, doi:10.1002/2015JC010812, 2015.

\bibitem[Kirillov et al.(2016)]{Kirillov_etal_2016}
Kirillov, S., Dmitrenko, I., Tremblay, B., Gratton, Y., Barber, D., and Rysgaard, S.: Upwelling of Atlantic water along the Canadian Beaufort Sea continental slope: Favorable atmospheric conditions and seasonal and interannual variations, J. Climate, 29, 4509--4523, doi.org/10.1175/JCLI-D-15-0804.1, 2016.

\bibitem[Kitchen et al.(1982)]{Kitchen_etal_1982}
Kitchen, J. C., Zaneveld, J. R. V., and Pak, H.: Effect of particle size distribution and chlorophyll content on beam attenuation spectra, Appl. Opt., 21, 3913--3918, doi:10.1364/AO.21.003913, 1982.

\bibitem[Knap et al.(1996)]{Knap_etal_1996}
Knap, A., Michaels, A., Close, A., Ducklow, H., and Dickson, A. (Eds.): Protocols for the Joint Global Ocean Flux Study (JGOFS) Core Measurements, JGOFS Report Nr. 19, vi+170 pp., Reprint of the IOC Manuals and Guides No. 29, UNESCO, 1996.

\bibitem[Lansard et al.(2012)]{Lansard_etal_2012}
Lansard, B., Mucci, A., Miller, L. A., Macdonald, R. W., and Gratton, Y.: Seasonal variability of water mass distribution in the southeastern Beaufort Sea determined by total alkalinity and $\delta^{18}O$, J. Geophys. Res., 117, C03003, doi:10.1029/2011JC007299, 2012.

\bibitem[Macdonald et al.(1998)]{Macdonald_etal_1998}
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, Marine Geology, 144(4), 255--273, doi:10.1016/S0025-3227(97)00106-0, 1998.

\bibitem[Martin et al.(2010)]{Martin_etal_2010}
Martin, J., Tremblay, J.-E., Gagnon, J., Tremblay, G., Lapoussi\`ere, A., Jose, C., Poulin, M., Gosselin, M., Gratton, Y. and Michel, C.: Prevalence, structure and properties of subsurface chlorophyll maxima in Canadian Arctic waters, Mar. Ecol. Prog. Ser., 412, 69--84, doi: 10.3354/meps08666, 2010.

\bibitem[Matsuoka et al.(2012)]{Matsuoka_etal_2012}
Matsuoka, A., Bricaud, A., Benner, R., Para, J., Semp\'{e}r\'{e}, R., Prieur, L., B\'elanger, S., and Babin, M.: Tracking the transport of colored dissolved organic matter in the Southern Beaufort Sea: relationship with hydrographic characteristics, Biogeosciences, 9, 925--940, doi:10.5194/bg-9-925-2012, 2012.

\bibitem[McClelland et al.(2012)]{McClelland_etal_2012}
McClelland, J. W., Holmes, R. M., Dunton, K. H., and Macdonald, R. W.: The Arctic Ocean Estuary, Estuar. Coast., 35, 353--368, doi:10.1007/s12237-010-9357-3, 2012.

\bibitem[McPhee(2013)]{McPhee_2013}
McPhee, M. G.: Intensification of Geostrophic Currents in the Canada Basin, Arctic Ocean, J. Clim., 26, 3130--3138, doi:10.1175/JCLI-D-12-00289.1, 2013.

\bibitem[Mol et al.(2018)]{Mol_etal_2018}
Mol, J., Thomas, H., Myers, P. G., Hu, X., and Mucci, A.: Inorganic carbon fluxes on the Mackenzie Shelf of the Beaufort Sea, Biogeosciences, 15, 1011,Äì-1027, doi:10.5194/bg-15-1011-2018, 2018.

\bibitem[Moore(2012)]{Moore_2012}
Moore, G. W. K.: Decadal variability and a recent amplification of the summer Beaufort Sea High, Geophys. Res. Lett., 39, L10807, doi:10.1029/2012GL051570, 2012.

\bibitem[Morel and Bricaud(1986)]{Morel_Bricaud_1986}
Morel, A. and Bricaud, A.: Inherent optical properties of algal cells, including picoplankton: Theoretical and experimental results, Can. Bull. Fish. Aquat. Sci., 214, 521-559, 1986.

\bibitem[O'Brien et al.(2006)]{OBrien_etal_2006}
O,ÄôBrien, 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, doi:10.1016/j.csr.2005.09.007, 2006.

\bibitem[O'Brien et al.(2011)]{OBrien_etal_2011}
O,ÄôBrien, M. C., Melling, H., Pedersen, T. F., and Macdonald, R. W.: The role of eddies and energetic ocean phenomena in the transport of sediment from shelf to basin in the Arctic, J. Geophys. Res., 116, C08001, doi:10.1029/2010JC006890, 2011.

\bibitem[Pickart(2004)]{Pickart_2004}
Pickart, R. S.: Shelfbreak circulation in the Alaskan Beaufort Sea: Mean structure and variability, J. Geophys. Res., 109, C04024, doi:10.1029/2003JC001912, 2004.

\bibitem[Reynolds et al.(2010)]{Reynolds_etal_2010}
Reynolds, R. A., Stramski, D., Wright, V. M., and Wo\'{z}niak, S. B.: Measurements and characterization of particle size distributions in

coastal waters, J. Geophys. Res., 115, C08024, doi:10.1029/2009JC005930, 2010.

\bibitem[Reynolds et al.(2016)]{Reynolds_etal_2016}
Reynolds, R. A., Stramski, D., and Neukermans, G.: Optical backscattering by particles in Arctic seawater and relationships to particle mass concentration, size distribution, and bulk composition, Limnol. Oceanogr., 61, 1869--1890, doi:10.1002/lno.10341, 2016.

~~\bibitem[Timmermans et al.(2003)]{Timmermans_etal_2003}
Timmermans, M. L., Garrett, C., and Carmack, E.: The thermohaline structure and evolution of the deep waters in the Canada Basin, Arctic Ocean, Deep-Sea Res. I, 50, 1305--1321, 2003.~~

\bibitem[Sallon et al.(2011)]{Sallon_etal_2011}
Sallon, A., Michel, C., and Gosselin, M.: Summertime primary production and carbon export in the southeastern Beaufort Sea during the low ice year of 2008, Polar Biol., 34, 1989--2005, doi:10.1007/s00300-011-1055-5, 2011.

\bibitem[Spall et al.(2014)]{Spall_etal_2014}
Spall, M. A., Pickart, R. S., Brugler, E. T., Moore, G. W. K., Thomas, L, Arrigo, K. R.: Role of shelfbreak upwelling in the formation of a massive under-ice bloom in the Chukchi Sea, Deep Sea Res. II, 105, 17--29, doi:10.1016/j.dsr2.2014.03.017, 2014.

\bibitem[Stramska and Stramski(2005)]{Stramska_Stramski_2005}
Stramska, M. and Stramski, D.: Variability of particulate organic carbon concentration in the north polar Atlantic based on ocean color observations with Sea-viewing Wide Field-of-view Sensor (SeaWiFS), J. Geophys. Res., 110, C10018, doi:10.1029/2004JC002762, 2005.

\bibitem[Stramski and Kiefer(1991)]{Stramski_Kiefer_1991}
Stramski, D. and Kiefer, D. A.: Light scattering by microorganisms in the open ocean, Prog. Ocenogr., 28, 4, 343--383, doi.org/10.1016/0079-6611(91)90032-H, 1991.

\bibitem[Stramski et al.(2008)]{Stramski_etal_2008}
Stramski, D., Reynolds, R. A., Babin, M., Kaczmarek, S., Lewis, M. R., R\"{o}ttgers, R., Sciandra, A., Stramska, M., Twardowski, M. S., Franz, B. A., and Claustre, H.: Relationships between the surface concentration of particulate organic carbon and optical properties in the eastern South Pacific and eastern Atlantic Oceans, Biogeosciences, 5, 171--201, doi:10.5194/bg-5-171-2008, 2008.

\bibitem[Stroeve et al.(2014)]{Stroeve_etal_2014}
Stroeve, J. C., Markus, T., Boisvert, L., Miller, J., and Barrett, A.: Changes in Arctic melt season and implications for sea ice loss, Geophys. Res. Lett., 41, 1216--1225, doi:10.1002/2013GL058951, 2014.

\bibitem[Timmermans et al.(2003)]{Timmermans_etal_2003}
Timmermans, M. L., Garrett, C., and Carmack, E.: The thermohaline structure and evolution of the deep waters in the Canada Basin, Arctic Ocean, Deep-Sea Res. I, 50, 1305--1321, 2003.

\bibitem[Stroeve et al.(2014)]{Stroeve_etal_2014}
Stroeve, J. C., Markus, T., Boisvert, L., Miller, J., and Barrett, A.: Changes in Arctic melt season and implications for sea ice loss, Geophys. Res. Lett., 41, 1216--1225, doi:10.1002/2013GL058951, 2014.

\bibitem[Tremblay et al.(2008))]{Tremblay_etal_2008}
Tremblay, J.-\'E., Simpson, K., Martin, J., Miller, L., Gratton, Y., Barber, D., and Price, N. M.: Vertical stability and the annual dynamics of nutrients and chlorophyll fluorescence in the coastal, southeast Beaufort Sea, J. Geophys. Res., 113, C07S90, doi:10.1029/2007JC004547, 2008.

\bibitem[Tremblay et al.(2011)]{Tremblay_etal_2011}
Tremblay, J.-\'E., B\'elanger, S., Barber, D. G., Asplin, M., Martin, J., Darnis, G., Fortier, L., Gratton, Y., Link, H., Archambault, P., Sallon, A., Michel, C., Williams, W. J., Philippe, B., and Gosselin, M.: Climate forcing multiplies biological productivity in the coastal Arctic Ocean, Geophys. Res. Lett., 38, L18604, doi:10.1029/2011GL048825, 2011.

\bibitem[Williams and Carmack(2008)]{Williams_Carmack_2008}
Williams, W. J. and Carmack, E. C.: Combined effect of wind-forcing and isobath divergence on upwelling at Cape Bathurst, Beaufort Sea, J. Mar. Res., 66 (5), 645--663, doi:10.1357/002224008787536808, 2008.

\bibitem[Williams et al.(2006)]{Williams_etal_2006}
Williams, W. J., Carmack, E. C., Shimada, K., Melling, H., Aagaard, K., Macdonald, R. W., Ingram, R. G.: Joint effects of wind and ice motion in forcing upwelling in Mackenzie Trough, Beaufort Sea, Cont. Shelf Res., 26, 2352--2366, 2006.

\bibitem[Williams et al.(2008)]{Williams_etal_2008}
Williams, W. J., Melling, H., Carmack, E. C., Ingram, R. G.: Kugmallit Valley as a conduit for cross-shelf exchange on the Mackenzie Shelf in the Beaufort Sea, J. Geophys. Res., 113, C02007, doi:10.1029/2006JC003591, 2008.

\bibitem[Wo\'{z}niak et al.(2010)]{Wozniak_etal_2010}
Wo\'zniak, S. B., Stramski, D., Stramska, M., Reynolds, R. A., Wright, V. M., Miksic, E. Y., Cichocka, M., Cieplak, A. M.: Optical variability in relation to particle concentration, composition, and size distribution in the nearshore marine environment at Imperial Beach, California, J. Geophys. Res., 115, C08027, doi:10.1029/2009JC005554, 2010.

\bibitem[Yamamoto-Kawai et al.(2008)]{Yamamoto-Kawai_etal_2008}
Yamamoto-Kawai, M., McLaughlin, F. A., Carmack, E. C., Nishino, S., and Shimada, K.: Freshwater budget of the Canada Basin, Arctic Ocean, from salinity, d18O, and nutrients, J. Geophys. Res., 113, C01007, doi:10.1029/2006JC003858, 2008.

\bibitem[Yang(2009)]{Yang_2009}
Yang, J.: Seasonal and interannual variability of downwelling in the Beaufort Sea, J. Geophys. Res., 114, C00A14, doi:10.1029/2008JC005084, 2009.

\end{thebibliography}

%% Since the Copernicus LaTeX package includes the BibTeX style file copernicus.bst,
%% authors experienced with BibTeX only have to include the following two lines:
%%
%% \bibliographystyle{copernicus}
%% \bibliography{example.bib}
%%
%% URLs and DOIs can be entered in your BibTeX file as:
%%
%% URL = {http://www.xyz.org/~jones/idx_g.htm}
%% DOI = {10.5194/xyz}

%% LITERATURE CITATIONS
%%
%% command & example result
%% \citet{jones90}| & Jones et al. (1990)
%% \citep{jones90}| & (Jones et al., 1990)
%% \citep{jones90,jones93}| & (Jones et al., 1990, 1993)
%% \citep[p.~32]{jones90}| & (Jones et al., 1990, p.~32)
%% \citep[e.g.,][]{jones90}| & (e.g., Jones et al., 1990)
%% \citep[e.g.,][p.~32]{jones90}| & (e.g., Jones et al., 1990, p.~32)
%% \citeauthor{jones90}| & Jones et al.
%% \citeyear{jones90}| & 1990

%% FIGURES

%% When figures and tables are placed at the end of the MS (article in one-column style), please add \clearpage
%% between bibliography and first table and/or figure as well as between each table and/or figure.

\clearpage

\begin{figure*}[t]
\includegraphics[width=~~12cm]{Fig1~~17.7cm]{Fig01_revision.pdf}
\caption{Map of study area with stations sampled along transect lines 100 to 700 during the ~~Malina~~MALINA expedition in 2009. CTD/Rosette water sampling was conducted on the 28 stations marked by stars with black borders. Black circles are the three locations selected for NCEP 10 m winds. The green square near station 140 indicates the location of the long-term mooring CA05 with a current meter at 178 m~~ or 202 m depth.~~. The cyan circles mark the locations for three of the profiles shown in Fig. ~~12.~~\ref{fig:deepSPM}. The fourth station, CB-21, was located 1\$^{\circ}\$ north of CB-27.}
\label{fig:MAP}
\end{figure*}

```
\begin{figure*}[t]
\includegraphics[width=12cm]{Fig217.7cm]{Fig02_revision.png}
\caption{Surface fieldsFields of water salinity (left panels) and
particulate beam attenuation coefficient at 660 nm, $c_\mathrm{p}(660)$,
(right panels) for (a--b) sea surface, (c--d) 30 m depth, and (e--f) 80 m
during the MALINA 2009 expedition.}
. Dashed contour lines in (a) are the fraction of meteoric water (\%) of
the freshwater.}
\label{fig:SSURF}
\end{figure*}

\begin{figure*}[t]
\includegraphics[width=12cm]{Fig317.7cm]{Fig03_revision.pdf}
\caption{
Sections of geostrophic current velocity (colours and white contours)
perpendicular to transect lines 100 (a), 200 (b), 300 (c), and 600 (d).
Note the changes in scale. The grey contour lines are for potential
temperature. Geopotential heights were referenced to 500 m. Positive
current values are generally for the direction perpendicular to the
transect lines (see Figure 1) either towards northwest (a) or west (b--c)
or southwest (d). The location of the current meter on the CA05 mooring
is shown in (a).}
\label{fig:GEOSTROPHIC}
\end{figure*}

\begin{figure*}[t]
\includegraphics[width=17.7cm]{Fig04_revision.pdf}
\caption{
Voltage readings from the chlorophyll fluorometer (left panels) and CDOM
fluorometer (right panels) for transects (a--b) 100, (c--d) 300 and (e--
f) 600.}
\end{figure*}

\label{fig:FLUO}
\end{figure*}

\begin{figure}[t]
\includegraphics[width=8.3cm]{Fig4.pdf}
17.7cm]{Fig05_revision.png}
\caption{{{
(a) POC to SPM ratio for surface samples within the study area and, (b)
relationship between POC to SPM ratio and meteoric water fraction of
freshwater in surface waters (see Fig. 2a), and relationship between
volume fraction of particles less than 1 $\mu$m in diameter to total
particle volume between 0.7 $\mu$m and 120 $\mu$m withand (c) salinity
measured with a Beckman Coulter Multisizer 3 during the MALINA 2009
expedition.}
, and (d) meteoric water fraction of freshwater. Values in (d) are
limited to surface waters.}
\label{fig:POC2SPM}
\end{figure}

\begin{figure*}[t]
\includegraphics[width=12cm]{Fig517.7cm]{Fig06_revision.pdf}
```

\caption{~~Relationship between~~
SPM and POC ~~to the~~as a function of particulate beam attenuation coefficient at 660 nm based on measurements from \textit{CCGS Amundsen} during the MALINA expedition in 2009 (a--b~~)~~), and ~~with~~as a function of the particulate beam attenuation coefficient at 676 nm measured with the AC-9 from the barge (c--d) (the latter data contain only surface samples). The dotted squares in (c) and (d) indicate axes limits in (a) and (b), respectively. The ~~colors~~colours of the data points indicate POC/SPM categories: mineral-dominated (red), mixed (blue), and organic-dominated (green).}
~~\end{figure*}~~

~~\begin{figure}[t]~~
~~\includegraphics[width=8.3cm]{Fig6.pdf}~~
~~\caption{(~~\label{fig:FIT}
\end{figure*}

~~a) Daily discharge for the Mackenzie River at the Arctic Red River location (10LC014). Data obtained from Environment Canada. (b) Weekly ice coverage for the Mackenzie Shelf area calculated using IceGraph 2.0 provided online by the Canadian Ice Service. Time periods for the four expeditions considered in this study are also indicated in color shades.}~~
~~\end{figure}~~

\begin{figure*}[t]
\includegraphics[width=~~12cm]{Fig7~~17cm]{Fig07_revision.pdf}
~~\caption{Ice coverage data from the Canadian Ice Service. The blue labels denote areas of first-year ice (,Äòf,Äô), multi-year ice (,Äòm,Äô) and new ice types: nilas (,Äòn,Äô), grey ice (,Äòg,Äô), grey-white ice (,Äògw,Äô), while numbers that follow indicate ice concentration in tenths (9+ indicates > 90 \%). The areas of the three ice types are also associated with colors; green for first-year ice, red for multi-year ice and purple for the new ice types, while the color shade relates to concentration.}~~
~~\end{figure*}~~

~~\begin{figure*}[t]~~
~~\includegraphics[width=12cm]{Fig8.pdf}~~
~~\caption{Progressive vector plots of (a) daily average wind (NCEP, 10 m) and (b) currents from mooring CA05, with insets for 2003--2004 and 2007--2008 data. Colors in (a) indicate daily average wind speeds shown in color bar, while in (b) the colors of each plot indicate either current speed, salinity or temperature as denoted next to the lines and shown in more detail in (c)--(e). The start of each month is indicated. For the insets in (b), showing 2003--2004 and 2007--2008 data, the colors indicate either temperature or salinity as denoted. The four blue circles in (a), marking 1 July 2004, 20 October 2007, 8 July 2008, and 7 August 2009, respectively, show the approximate times of the ship-based transect sampling across the Mackenzie shelf break used in this study. The black line shows the direction along the shelfbreak referenced to True North. Time series for 2008--2009 for (c) current speed (colors are current directions), (d) salinity at two depths on the mooring (note different scale), and (e) temperature at two depths and turbidity (green line) at~~

```
57 m (the turbidity at 178 m remained near zero throughout the time
series).}
\end{figure*}

\begin{figure*}[t]
\includegraphics[width=12cm]{Fig9.pdf}
\caption{Sections of geostrophic current velocity (colors and white
contours) perpendicular to transect lines 100 (a), 200 (b), 300 (c), and
600 (d). Note the changes in scale. The grey contour lines are for
potential temperature. Geopotential heights were referenced to 500 m.
Positive current values are generally for the direction perpendicular to
the transect lines (see Figure 1) either towards northwest (a) or west
(b--c) or southwest (d).}
\end{figure*}
\caption{

\begin{figure*}[t]
\includegraphics[width=12cm]{Fig10.pdf}
\caption{Concentration of suspended particulate matter, SPM, calculated
from measurements of particulate beam attenuation coefficient at 660 nm,
$c_\mathrm{p}(660)$, -using Eq. 2 for lines 100, 300 and 600 during
different field campaigns in 2004, 2007, 2008, and 2009, as indicated.}
\label{fig:SPM}
\end{figure*}

\begin{figure*}[t]
\end{figure*}

\begin{figure*}[t]
\includegraphics[width=12cm]{Fig1117cm]{Fig08_revision.pdf}
\caption{
As Fig. 10\ref{fig:SPM} but for measurements of water temperature
(colorscolours) and salinity (contour lines).}
\label{fig:TS}
\end{figure*}

\begin{figure*}[t]
\end{figure*}

\begin{figure*}[t]
\includegraphics[width=12cm]{Fig1217.7cm]{Fig09_revision.pdf}
\caption{
Vertical profiles of (a) suspended particulate matter, SPM, calculated
from particulate beam attenuation coefficient at 660 nm,
$c_\mathrm{p}(660)$, and (b) temperature, $T$, and salinity, $S$, at
selected ,Äúdeep,Äù stations. Inserts (c) and (d) show transmissometer
data (converted to SPM using Eqs. 1--2) that were collected in Canada
Basin during 21--23 September 2009 and made available by the Beaufort
Gyre Exploration Program based at the Woods Hole Oceanographic
Institution (http://www.whoi.edu/beaufortgyre) in collaboration with
researchers from Fisheries and Oceans Canada at the Institute of Ocean
Sciences. Insert (e) shows a close up of the potential temperature,
$\theta$, and $S$ for CB-23, CB-27 and CB-21 at the interface to the
```

```latex
Canada Basin Bottom Water layer. Grey horizontal lines indicate bottom
depths and are underlain by station numbers (see Fig. 1 for locations).}
\label{fig:deepSPM}
\end{figure*}

\begin{figure}[t]
\includegraphics[width=12cm]{Fig10_revision.pdf}
\caption{
(a) Daily discharge for the Mackenzie River at the Arctic Red River
location (10LC014). Data obtained from Environment Canada. (b) Weekly ice
coverage for the Mackenzie Shelf area calculated using IceGraph 2.0
provided online by the Canadian Ice Service. Time periods for the %four
three expeditions considered in this study are also indicated in colour
shades.}
\label{fig:RD-SIC}
\end{figure}

\begin{figure*}[t]
\includegraphics[width=7cm]{Fig11_revision.png}
\caption{
Ice coverage data from the Canadian Ice Service. The blue labels denote
areas of first-year ice (,Äòf,Äô) and multi-year ice (,Äòm,Äô), while
numbers that follow indicate ice concentration in tenths (9+ indicates >
90 \%). The areas of the two ice types are also associated with colours;
green for first-year ice, and red for multi-year ice. The colour shade
relates to concentration.}
\label{fig:CIS}
\end{figure*}

\begin{figure*}[t]
\includegraphics[width=17.7cm]{Fig12_revision.pdf}
\caption{
Progressive vector plots of (a) daily average wind (NCEP, 10 m) and (b)
currents from mooring CA05, with inset for 2003--2004 CASES data.
Colours in (a) indicate daily average wind speeds shown in colour bar.
The blue circles in (a) and (b) show the approximate times of the ship-
based transect sampling across the Mackenzie shelf break used in this
study. The black line shows the direction along the shelfbreak referenced
to True North. In (b), the same vector plot for currents is shown three
times, but the colours of each plot indicate either current speed,
salinity or temperature as denoted next to the lines and shown in more
detail in (c) and (d). The start of each month is indicated.
For the inset in (b) showing 2003--2004, the colours indicate salinity as
denoted.
Time series for 2008--2009 for (c) current speed (colours are current
directions), (d) salinity (red) and temperature (blue) at 178 m depth.}
\label{fig:VECTOR}
\end{figure*}

\begin{table}[t]
\caption{Salinity, saline end-member, meteoric and sea ice melt fractions
(\%), and meteoric water percentage of freshwater content (MW\% =
$f_{MW}/(f_{MW}+f_{SIM})\times 100$) for surface seawater samples
obtained at matching station locations during CASES 2004 and MALINA 2009.
```

```
A few matching station were also sampled during IPY-CFL 2008. The samples
were collected with Niskin bottles on a CTD-Rosette. The fraction of the
saline end-member ($f_{PSW}$) represents Pacific Summer Water with a
salinity of 31.5 PSU.}
\begin{tabular}{ c | c | c c c c c }
\tophline
Cruise  & Station & Salinity & $f_{PSW}$ & $f_{MW}$ & $f_{SIM}$ & MW\%
\\
\middlehline
CASES  & 110 & 25.4 & 80.1 & 6.6 & 13.3 & 34.8 \\
2004   & 140 & 27.8 & 84.6 & 5.1 & 10.4 & 33.2 \\
           & 150 & 29.3 & 89.1 & 7.5 &   3.4 & 68.6  \\
           & 170 & 29.8 & 91.0 & 7.0 &   2.1 & 77.5  \\
           & 320 & 29.4 & 89.2 & 1.3 &  9.4  & 12.2  \\
           & 340 & 27.1 & 81.4 & 3.4 & 15.2 & 18.3  \\
           & 360 & 25.1 & 79.9 & 19.6 & 0.5 & 97.5  \\
           & 380 & 24.8 & 76.2 & 19.5 & 4.3 & 82.0  \\
           & 390 & 25.4 & 78.8 & 20.4 & 0.8 & 96.3 \\
           & 660 & 15.9 & 48.5 & 40.9 & 7.7 & 79.3  \\
           & 670 & 16.9 & 52.6 & 40.2 &  7.2 & 84.7  \\
           & 690 &   8.8 & 26.0 & 60.5 & 13.5 & 81.8  \\
\middlehline
IPY-CFL & 110 & 28.2 & 85.1 & 4.9 & 10.1 &  32.5 \\
2008    & 140 & 28.2 & 85.1 & 4.3 & 10.6 &  28.8  \\
            & 160 & 30.3 & 91.6 & 3.7 &   4.7 &  44.4  \\
    & 320$^*$ & 26.3 & 79.5 & 12.4 & 8.1  & 60.5  \\
    & 340$^*$ & 25.0 & 75.5 & 17.5 & 7.1  & 71.1  \\
            & 390 & 29.4 & 88.9 & 11.0 & 0.2 & 98.6  \\
\middlehline
MALINA & 110 & 28.9 & 86.6 & 4.8 & 8.6 & 35.6  \\
 2009   & 150 & 29.4 & 89.4 & 4.9 & 5.7 & 46.1  \\
            & 170 & 29.3 & 89.9 & 6.3 & 3.9 & 62.0  \\
            & 320 & 26.5  & 79.2 & 6.3 & 14.5 & 30.2  \\
            & 340 & 26.9 & 79.7 & 4.5 & 15.6 & 22.2  \\
            & 360 & 26.5 & 78.4 & 4.6 & 17.0 & 21.2 \\
            & 380 & 27.7 & 83.1 & 6.1 & 10.8 & 36.0 \\
            & 390 & 27.2 & 83.5 & 7.8 & 8.7 & 47.2  \\
            & 660 & 21.9 & 63.9 & 17.0 & 19.1 & 47.1  \\
            & 670 & 23.4 & 68.0 & 15.3 & 16.7 & 47.8  \\
            & 690 & 27.2 & 67.2 & 18.6 & 14.2 & 56.7  \\
\bottomhline
\end{tabular}
\belowtable{$^*$Approximately 5 nm south of station, which is half way to
next station} % Table Footnotes
\end{table}

\end{document}
```