A Pan-Arctic Algorithm to Estimate Dissolved Organic Carbon Concentrations From Colored Dissolved Organic Matter Spectral Absorption

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Key Points:

- Spectral properties of colored dissolved organic matter can predict dissolved organic carbon concentrations across a range of Arctic aquatic systems
- We developed a pan-Arctic algorithm from a comprehensive data set spanning from rivers to the deep Arctic waters
- The algorithm provides robust estimates allowing for reproduction of regional features such as vertical profiles and mixing lines

Supporting Information:

Supporting Information may be found in the online version of this article.

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A Pan-Arctic Algorithm to Estimate Dissolved Organic Carbon Concentrations From Colored Dissolved Organic Matter Spectral Absorption

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Abstract Sampling for dissolved organic carbon (DOC) in the Arctic is challenging given the limited access and because it is not yet possible to measure with instruments deployed in situ. Compared to DOC, colored dissolved organic matter (CDOM) absorption spectroscopy is an easy-to-measure, relatively quick and cost-effective approach which is often closely related to DOC concentrations in water samples. Here we present an algorithm based on quantitative and qualitative metrics of CDOM to provide DOC estimates derived from a Pan-Arctic data set (n = 3,302) spanning rivers to deep ocean, with DOC ranging between 31 and 1,958 µM. The algorithm provided robust DOC estimates ($r^2 = 0.94$; $p < 0.0001$) and could reproduce DOC profiles and mixing plots across different locations in the Arctic Ocean. Besides its simplicity, this method is capable of capturing the extremely broad range of DOC within the strong gradients observed between Arctic riverine and marine systems.

Plain Language Summary Surface waters in the Arctic Ocean have high content of dissolved organic carbon (DOC), which plays an important role in CO_2 fluxes and absorbing heat, thus warming the ocean. Measuring DOC requires resource-intensive lab analysis. The optical properties of colored dissolved organic matter (CDOM) are easier, quick and cost-effective to measure, and can therefore be sampled at a higher frequency or with autonomous sensors. Here we develop an algorithm that uses CDOM optical properties to estimate DOC concentrations across the entire Arctic Ocean, spanning from rivers (high DOC) to the deep waters (low DOC). The algorithm provides reliable estimates and can reproduce regional features, which shows that the method is effective and can be employed to increase sampling efforts for DOC in remote Arctic waters.

1. Introduction

The amount of carbon bound as dissolved organic matter (DOM) in the ocean represents a reservoir comparable in magnitude to that as CO_2 in the atmosphere (Hansell et al., 2009). Climate change is altering the distribution and flow of carbon between reservoirs, and it is therefore of interest to understand and trace the production, distribution, and turnover of dissolved organic carbon (DOC) in the ocean. For this reason, DOC has been selected by the Intergovernmental Oceanographic Commission, Global Ocean Observing System, as one of a list of Essential Ocean Variables (EOV). These are parameters that are deemed important for assessment and projection of climate and ocean health. A fraction of DOM absorbs light at ultraviolet (UV) and visible wavelengths. This is referred to as colored (or chromophoric) DOM (CDOM), and contributes to another cross cutting EOV, ocean color (remotely sensed spectral reflectance). CDOM light absorption influences light penetration and energy absorption in the surface ocean and for the Arctic, where CDOM levels are high, the latter can influence ocean heating and sea ice dynamics (Granskog et al., 2015; Hill, 2008; Pavlov et al., 2015; Soppa et al., 2019).

There are widespread, strong gradients in DOM across the Arctic Ocean. Some unique characteristics of the Arctic Ocean are its relatively small size and strong stratification of surface waters linked to sea ice. This results in a broad distribution of elevated concentrations of riverine DOM in surface waters (<500 m), which contrasts other ocean basins where river supply is rapidly diluted. This terrestrial DOM signal is superimposed on a background of oceanic DOM consisting either of aged extensively processed or recently derived material from marine organisms. The largest allochthonous supply of DOC to the Arctic Ocean is from inflowing Atlantic waters

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(Anderson & Amon, 2015). The considerable difference in water flux compensates for the fact that DOC concentrations are an order of magnitude lower in ocean waters (~50–60 μM) than rivers. Although the DOC budget appears balanced there is mineralization and changes in the quality of DOM, and the net result is that some of the terrestrial carbon supplied by rivers is exported to the north Atlantic. Current estimates of marine DOC production indicate that it is comparable to the terrestrial DOC supply by rivers. In order to follow how changing conditions in the Arctic, such as retreat of sea ice, altered stratification and increased river discharge (Nummelin et al., 2016) will influence the role of DOC in the carbon budget it is important to improve temporal and spatial coverage of measurements.

DOC measurements are restricted to discreet sampling and spatial and temporal coverage is therefore sparse and largely limited to that of water sampling programs. CDOM measurements are optical and therefore well suited for a wide variety of sensor platforms including, remote sensing (Juhls et al., 2022; Matsuoka et al., 2013), shipborne underway surface sampling (Dall'Olmo et al., 2017; Guay et al., 1999) and vertical profiling (Amon et al., 2003; Chen, 1999), and use on autonomous oceanographic platforms (Laney et al., 2014; Stedmon et al., 2021). A fraction of CDOM emits blue fluorescence when excited by UV light and therefore fluorometers have until now been the most commonly deployed sensors to measure DOM in situ. This can provide a first order indication of DOM abundance but is often difficult to link to DOC as the relationship will vary depending on DOM character (origin or extent of processing). An improved relationship can be derived by including spectral measurements, where changing DOM characteristics can be taken into account (Fichot & Benner, 2011; Gonçalves-Araujo et al., 2020; Shen et al., 2016). Many aromatic organic compounds absorb light at UV wavelengths, and it therefore makes sense to attempt to link both the intensity (CDOM absorption at a specific wavelength (λ), $a\text{CDOM}_{\lambda}$), and spectral shape of absorption in the UV, to DOC concentration.

Absorption intensities from selected wavelengths can be used to improve the prediction of DOC (Fichot & Benner, 2011; Shen et al., 2016), going beyond a simple linear correlation between $a_{\text{CDOM}}(\lambda)$ and DOC (Massicotte et al., 2017). For example, Fichot and Benner (2011), hereafter FB2011 (Table S1 in Supporting Information S1), performed multiple linear regressions of log-transformed DOC concentrations against log-transformed $a_{\text{CDOM}}(275)$ and $a_{\text{CDOM}}(295)$ to surface waters from the Beaufort Sea ($n = 33$), and additional segregation of model fit depending on high or low CDOM regimes. The approach was later adapted and refined to extend coverage to the North American sector of the Arctic Ocean (Shen et al., 2016; hereafter SH2016; Table S1 in Supporting Information S1) using a larger number of observations ($n = 755$). An alternative approach is to incorporate CDOM's qualitative information by characterizing the shape of the UV spectral absorption by fitting an exponential slope (S), which has been linked to DOM origin, molecular weight and degradation state (Granskog, 2012; Helms et al., 2008). Across a range of aquatic systems there is often a negative relationship between CDOMs spectral slope and the carbon specific absorption, with old, processed DOM having a high spectral slope (absorbance essentially dominated by UV only) and low color per unit carbon, and "fresh" terrestrial and marine DOM having contrasting properties (Stedmon & Nelson, 2015). We have recently utilized this phenomenon to derive an algorithm to link CDOM absorption to DOC in the Arctic, using a timeseries from the Fram Strait (Gonçalves-Araujo et al., 2020), hereafter GA2020 (Table S1 in Supporting Information S1). Specifically, the approach characterizes the nonlinear relationship between the CDOM absorption slope between 275 and 295 nm ($S_{275-295}$) and the ratio of DOC to $a\text{CDOM}_{350}$ ($\text{DOC}/a_{\text{CDOM}}(350)$), which can then be inverted to predict DOC from measurements of CDOM absorption alone. The central assumption is that the relationship between CDOM absorption and DOC concentration will change depending on the DOM quality. DOM across the Fram Strait has contrasting properties, reflecting the gradient that can be found in the central Artic (Granskog et al., 2012; Stedmon et al., 2011), with DOM in the outflow to the west characterized by terrestrial DOM, the inflow to the east by marine DOM, while deeper waters have older processed DOM (Gonçalves-Araujo et al., 2016; Makarewicz et al., 2018). Here we expand the data coverage to test the performance across the greater Arctic region. If successful, this will present an opportunity of adapting existing sensor technology to greatly expand spatial and temporal coverage of DOC measurements in the Arctic Ocean.

2. Data and Employed Methodology

2.1. Data Set

An Arctic DOM data set was compiled from published studies consisting of 3,302 observations covering the full range from high riverine concentrations to low DOM oceanic waters (Figure 1, Table 1). A minimum requirement

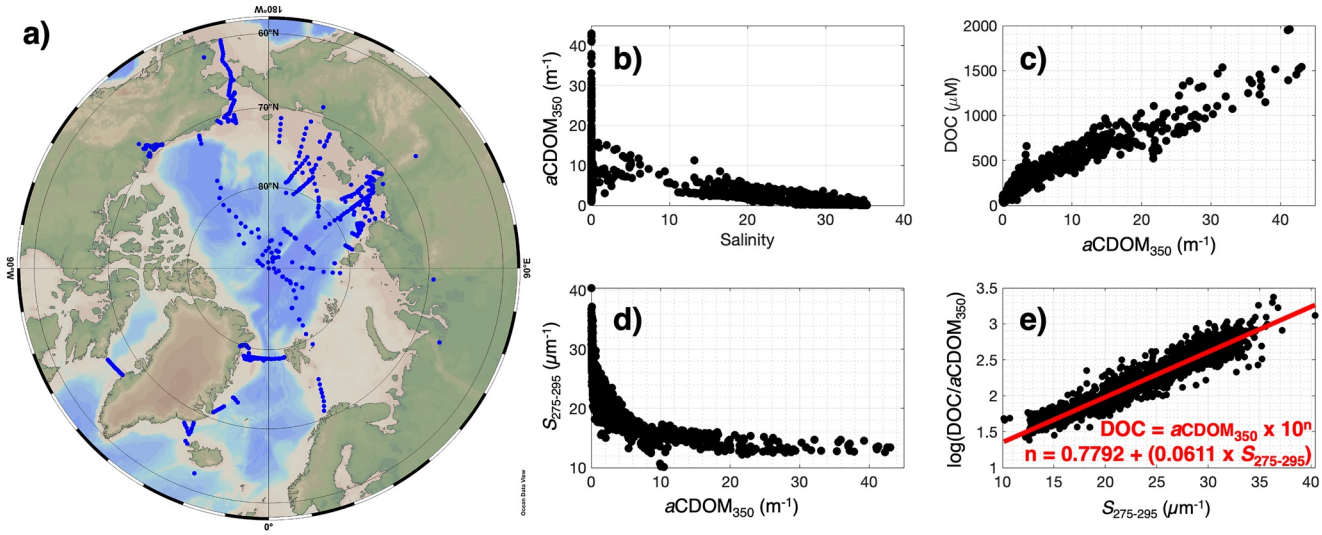

Figure 1. (a) Map showing the locations of sampling stations for the observations used in this study. Produced with Ocean Data View (Schlitzer, 2021). Scatter plots for (b) salinity versus $a_{CDOM}(350)$, (c) $a_{CDOM}(350)$ versus dissolved organic carbon (DOC), (d) $a_{CDOM}(350)$ versus $S_{275-295}$, and (e) $S_{275-295}$ and log(DOC/$a_{CDOM}(350)$). The red line in (e) represents the linear regression used to derive the DOC algorithm in this study, following the approach used for the GA2020 algorithm (Gonçalves-Araujo et al., 2020).

was DOC concentration, CDOM absorption (either spectra or only $a_{CDOM}(350)$), $S_{275-295}$ (if spectra were not provided) and geographical coordinates. CDOM spectra were available for 2,967 of the 3,302 observations. For the majority of the samples ($n = 2{,}676$), additional ancillary data such as sampling depth and salinity were available. Where necessary, DOC concentrations were converted to molarity, CDOM absorbance was converted to Napierian absorption coefficients (m^{-1}), and the UV spectral slope ($S_{275-295}$) was calculated.

2.2. Data Coverage

The observations were distributed across the entire Arctic, spanning a wide range of environmental conditions (Table 1, Figure S1 in Supporting Information S1). Both Eurasian and Amerasian Basins were covered, however, the latter is underrepresented due to lack of available data containing all the minimum required information needed for this study. Observations range from inland riverine waters, to estuarine, shelf seas, and open ocean waters, covering a comprehensive environmental gradient and encompassing most of the major endmembers and major water masses present in the Arctic Ocean, therefore covering the full salinity range. Further, surface waters under influence of sea ice melt, as well as waters from the deep ocean were included, spanning a depth range from 0 to ca. 5,000 m depth. With respect to DOM, the observations covered high DOM content riverine and estuarine waters, with high DOC and $a_{CDOM}(350)$, and typically low $S_{275-295}$. Shelf waters presented intermediate and variable range values for DOM-related parameters, which are mostly related to the variable hydrographic dynamics observed in those domains (Gonçalves-Araujo et al., 2015a; Juhls, Lizotte et al., 2019; Juhls, Overduin, Gonçalves-Araujo et al., 2019; Juhls, Overduin, Hölemann, et al., 2019; Massicotte et al., 2017). Finally, the open ocean waters were characterized by high salinity, and low DOM content, and variable $S_{275-295}$ (Gonçalves-Araujo et al., 2020; Shen et al., 2016; Stedmon et al., 2011).

2.3. DOC Prediction From CDOM

The approach used by GA2020 rests on the following findings: in regions in close proximity to rivers, linear relationships between $a_{CDOM}(350)$ and DOC often can be found (Gonçalves-Araujo et al., 2015a; Spencer et al., 2012; Vodacek et al., 1997), which allows for reliable DOC predictions with two endmembers (Fichot & Benner, 2011). In regions with two or more endmembers of more comparable DOC concentrations (i.e., shelf seas and oceanic waters), these relationships are rather difficult to derive (Figure 1c), since there might be two pools of similar concentration/intensity but different ratio of absorption to DOC (carbon specific absorption coefficient, a_{CDOM}*) (Gonçalves-Araujo et al., 2020). However, a_{CDOM}* is inversely correlated to $S_{275-295}$ (Figure 1d), which can

Table 1
Summary of Data Used (and Respective References to Access the Data) to Derive the Algorithm Presented in This Study, Along With the Number of Observations Derived From Each Data Set/Study (n) and the Ranges for Each Relevant Parameter Used in This Study: Depth (m), Salinity, Dissolved Organic Carbon (DOC) (μM), Colored Dissolved Organic Matter (CDOM) $a_{CDOM}(350)$ (m^{-1}) and $S_{275-295}$ (μm^{-1})

Cruise/Location and reference	*n*	Depth[a] (m)	Salinity[b]	DOC (μM)	$a_{CDOM}(350)$ (m^{-1})	$S_{275-295}$ (μm^{-1})
Arctic Great Rivers Observatory (AGRO)						
Shiklomanov et al. (2018)	290	Surface	River	175–1,958	0.95–43.04	12.5–25.0
Davis Strait 2013						
Gonçalves-Araujo et al. (2016)	138	1–1,027	31.40–34.87	39–75	0.06–0.35	22.1–33.7
Fram Strait 2009, 2010, 2012, 2016						
Granskog et al. (2012, 2020)	606	1–2679	23.22–35.15	37–222	0.05–0.86	19.7–36.8
Gonçalves-Araujo et al. (2020)						
NABOS 2018						
Gonçalves-Araujo et al. (2023a)	318	0–250	27.38–34.90	29–177	0.09–2.41	14.3–38.0
Herschel Island						
Fritz et al. (2023)	147	0–60	11.10–32.70	76–321	0.40–3.27	18.2–24.0
Transarktika						
Hölemann et al. (2020)	162	2–330	17.10–34.76	60–346	0.23–6.07	15.0–28.2
Transdrift XIX						
Hölemann et al. (2019c)	79	2–75	13.19–34.07	58–341	0.50–6.92	17.7–27.5
Transdrift XXI						
Hölemann et al. (2019b)	24	2–23	9.40–31.02	144–522	1.89–8.58	16.8–21.5
Transdrift XXII						
Hölemann et al. (2019d)	108	2–320	19.75–34.86	52–288	0.15–4.29	18.3–32.9
Transdrift XVII						
Hölemann et al. (2019a)	102	2–1,116	25.67–34.91	44–158	0.03–1.74	15.5–36.3
Laptev Sea						
Juhls et al. (2019)	74	2–10	13.19–32.56	91–341	0.49–6.93	17.7–26.7
Lena River						
Juhls et al. (2020)	73	Surface	River	411–1,517	9.82–39.26	14.1–17.3
Lena Delta 2013						
Gonçalves-Araujo et al. (2015b)	56	0–28	0.90–32.63	109–732	0.94–15.72	15.5–21.4
Arctic Ocean						
Hansell et al. (2021)	188	2–4,130	17.53–34.96	44–141	0.01–1.10	10.6–43.2
Makenzie Delta Region						
Juhls et al. (2022)	120	0.3–1.5	0.12–30.63	142–659	0.81–10.69	10.1–22.0
Juhls, Lizotte, et al. (2019)						
Central Arctic (PS94)						
Hansell (2017)	531	2–4,959	27.19–35.18	45–143	0.05–1.22	21.7–40.4
Gonçalves-Araujo et al. (2023b)						
East Greenland Shelf 2012						
Gonçalves-Araujo et al. (2016)	182	3–1,877	27.30–35.21	48–91	0.07–0.47	19.7–32.5
North Pacific						
Nelson et al. (2010)	9	9–1,911	34.99–35.29	47–58	0.07–0.12	26.6–34.3
Massicotte et al. (2017)						
Bering Sea/Strait						

Table 1
Continued

Cruise/Location and reference	*n*	Depth[a] (m)	Salinity[b]	DOC (μM)	$a_{CDOM}(350)$ (m^{-1})	$S_{275-295}$ (μm^{-1})
Tanaka et al. (2016)	95	5	26.85–32.43	61–110	0.13–0.75	22.4–35.2
Nishioka et al. (2020)						
Summary	**3,302**	**0–4,959**	**0–35.29**	**31–1,958**	**0.01–43.04**	**10.1–40.4**

[a]Some studies had their observations conducted at the surface and no actual sampling depth was reported. For those, we have adapted a sampling depth of 0. [b]For practical purposes, when salinity at river sites was not measured and it was assumed to be 0.

thus be employed as a weighting factor for the DOM origin (Gonçalves-Araujo et al., 2020; Helms et al., 2008; Stedmon & Markager, 2001; Stedmon & Nelson, 2015).

To derive DOC from CDOM properties, firstly a linear regression is performed between the logarithm of absorption normalized DOC and $S_{275-295}$ (Figure 1e) (Equation 1),

$$\log_{10}\left(\frac{\mathrm{DOC}}{a_{\mathrm{CDOM}}(350)}\right) = C + (M \times S_{275-295}), \quad (1)$$

which is then rearranged to estimate DOC (Equation 2)

$$p\mathrm{DOC} = a_{\mathrm{CDOM}}(350) \times 10^{(C+(M\times S_{275-295}))}. \quad (2)$$

For the combined data set in this study, we found the equation's coefficients to be $C = 0.7792$ and $M = 0.0611$ (Figure 1e; Table S1 in Supporting Information S1; $r^2 = 0.83$; $n = 3{,}302$; $p < 0.00001$).

2.4. Algorithm Validation and Performance Assessment

To assess the robustness of the derived relationship, a subset of half the data was randomly sampled, used to derive the model and then predict DOC for the whole data set. This was repeated 1,000 times. Each of the 1,000 individual pDOC data sets were tested against measured DOC by employing a Kruskal-Wallis H test, considering a significance of 1%. All 1,000 simulations did not significantly differ from the measured data set ($p < 0.01$) and did not differ among themselves (Figure S2 in Supporting Information S1), therefore showing the applicability/robustness of the fitted model.

To assess the performance of the algorithm for predicting DOC concentrations, the regression slope (β), coefficient of determination (r^2) and p-value were estimated through linear regression model fitting comparing measured to predicted DOC values. Additionally, to complement the statistics reported for the regression models and to compare measured and predicted DOC concentrations, Kruskal-Wallis H tests were performed. This approach was applied both in the algorithm development and validation phase. All statistical analyses were performed in Matlab®.

3. Results and Discussion

The good performance of the log-linear Pan-Arctic algorithm can be gauged by the significant linear regression model and through the r^2 and β values being both close to 1, as observed for the DOC versus pDOC plots (Figure 2a). The performance of the log-linear algorithm was much better (i.e., greater r^2 and β) than a linear regression of DOC with $a_{CDOM}(350)$ (Figure 2b) and it is clear that the inclusion of $S_{275-295}$ as an explanatory variable accounting for differences in DOM quality, is beneficial. Although significant correlations between CDOM and DOC are frequently reported, they can be expected to vary both geographically and temporally. For instance, two studies conducted in the Laptev Sea in different sampling periods reported different CDOM versus DOC relationships (Gonçalves-Araujo et al., 2015a; Juhls, Lizotte et al., 2019; Juhls, Overduin, Gonçalves-Araujo et al., 2019; Juhls, Overduin, Hölemann, et al., 2019). This makes the use of CDOM absorption as a proxy for DOC particularly challenging as it may require both regional and seasonal parametrizations.

Comparing the log-linear algorithm published for the Fram Strait (GA2020, Figure 2c) to measured DOC concentrations showed similar high consistency ($r^2 = 0.92$), however with lower accuracy ($\beta = 0.82$). This poorer

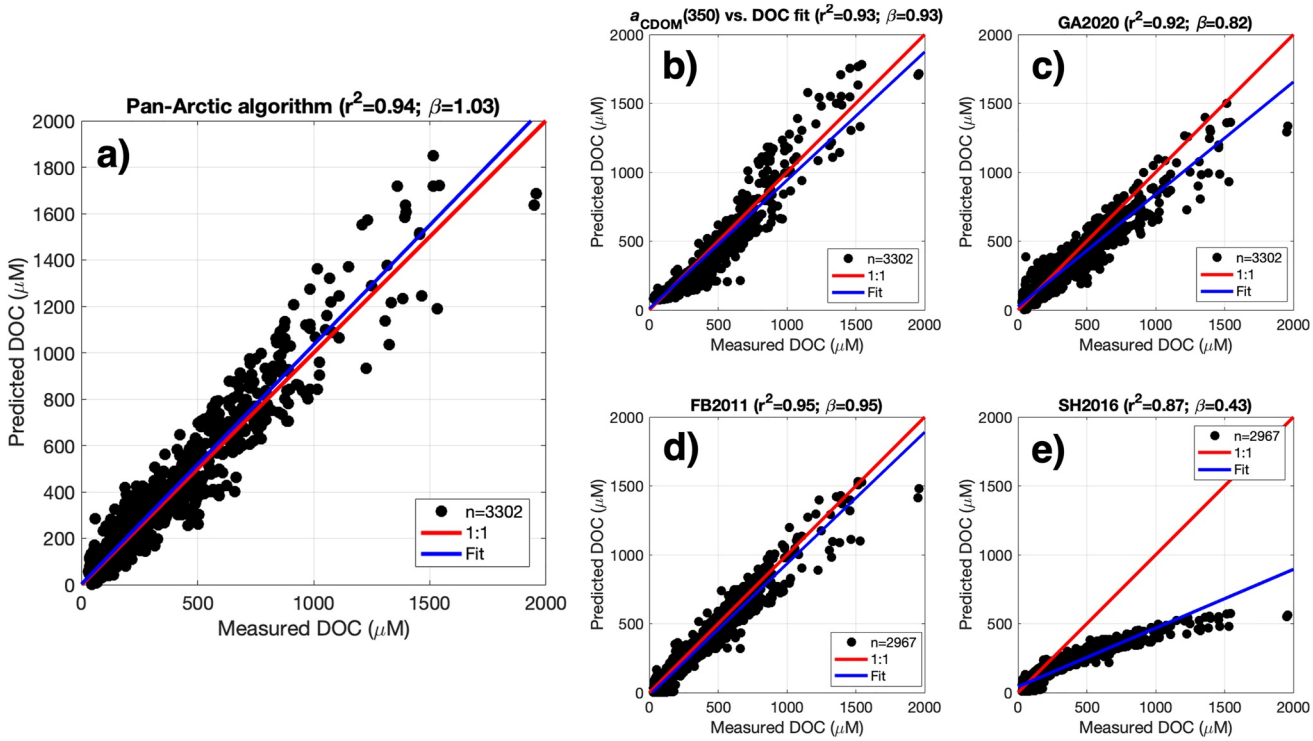

Figure 2. Scatter plots for measured (*x*-axis) versus predicted dissolved organic carbon (DOC) (*y*-axis) (in μM) for (a) the Pan-Arctic algorithm developed in this study, (b) a single linear regression between $a_{CDOM}(350)$ and DOC, (c) the Fram Strait algorithm (Gonçalves-Araujo et al., 2020; GA2020), (d) the Beaufort Sea algorithm (Fichot & Benner, 2011; FB2011) and (e) the North American Arctic Basin algorithm (Shen et al., 2016; SH2016). Red lines indicate the 1:1 line and the linear fit is presented as a blue line. In the titles, the r^2 and regression slope (β) for each plot are provided individually. Note the reduced number of observations for fitting FB2011 and SH2016 (d), (e) due to lack of available colored dissolved organic matter spectra in some data sets.

performance was already expected and was one of the motivations for developing a Pan-Arctic algorithm, since the GA2020 algorithm was developed based on much narrower range of DOC concentrations (ranging from 37 to 222 μM), compared to the range observed in this study (31–1,958 μM). Indeed, the Fram Strait algorithm underestimated DOC concentrations at high DOC, showing that the Pan-Arctic algorithm is a remarkable improvement, especially for riverine, estuarine, and coastal environments with higher DOC concentrations (see Figure 2).

FB2011 (Fichot & Benner, 2011) and SH2016 (Shen et al., 2016) developed approaches that fit multiple linear regressions to log-linearized DOC concentrations against log-linearized $a_{CDOM}(275)$ and $a_{CDOM}(295)$. When applying SH2016 to our data set, it performed poorly (Figure 2e). This could be because their observations were restricted to low DOC concentrations (<129 μM), thus, suppressing the effects of high DOC supplied by major Arctic rivers. FB2011, on the other hand, was developed based on coastal and shelf observations in the Beaufort Sea under influence of the Mackenzie River outflow, reaching values of 600 μM. Therefore, the FB2011 method performed well and provided robust and accurate DOC estimates (Figure 2d), however, it still performed slightly poorer than our new Pan-Arctic algorithm (i.e., β closer to 1 for the Pan-Arctic algorithm). In their study, Fichot and Benner (2011) have explored non-linear fitting to a_{CDOM} and $S_{275-295}$ but found the best results to be provided by the method they presented, which was developed through exploring multiple linear regression fittings. Here we show that fitting a linear regression to log-transformed $a_{CDOM}(350)$ and $S_{275-295}$ provided as good DOC predictions, however with an improved β value (Figure 2), which demonstrates the improvement of the Pan-Arctic algorithm. Notably the Pan-Arctic algorithm considers a much broader range of environments and, consequently, DOC concentrations. Additionally, the FB2011 and SH2016 algorithms are presented as two equations, depending on the $a_{CDOM}(275)$ values, thus requiring adjustments in algorithms' coefficients according to thresholds presented in their studies (see Table S1 in Supporting Information S1). Those thresholds (and consequently, the coefficients) differed between the two methods: 3.5 and 1.42 m^{-1} for FB2011 and SH2016, respectively (Fichot & Benner, 2011; Shen et al., 2016). Here we have developed a simpler method that works across the full range of CDOM and DOC values reported in the data sets (both for deriving the algorithm and for posterior validation).

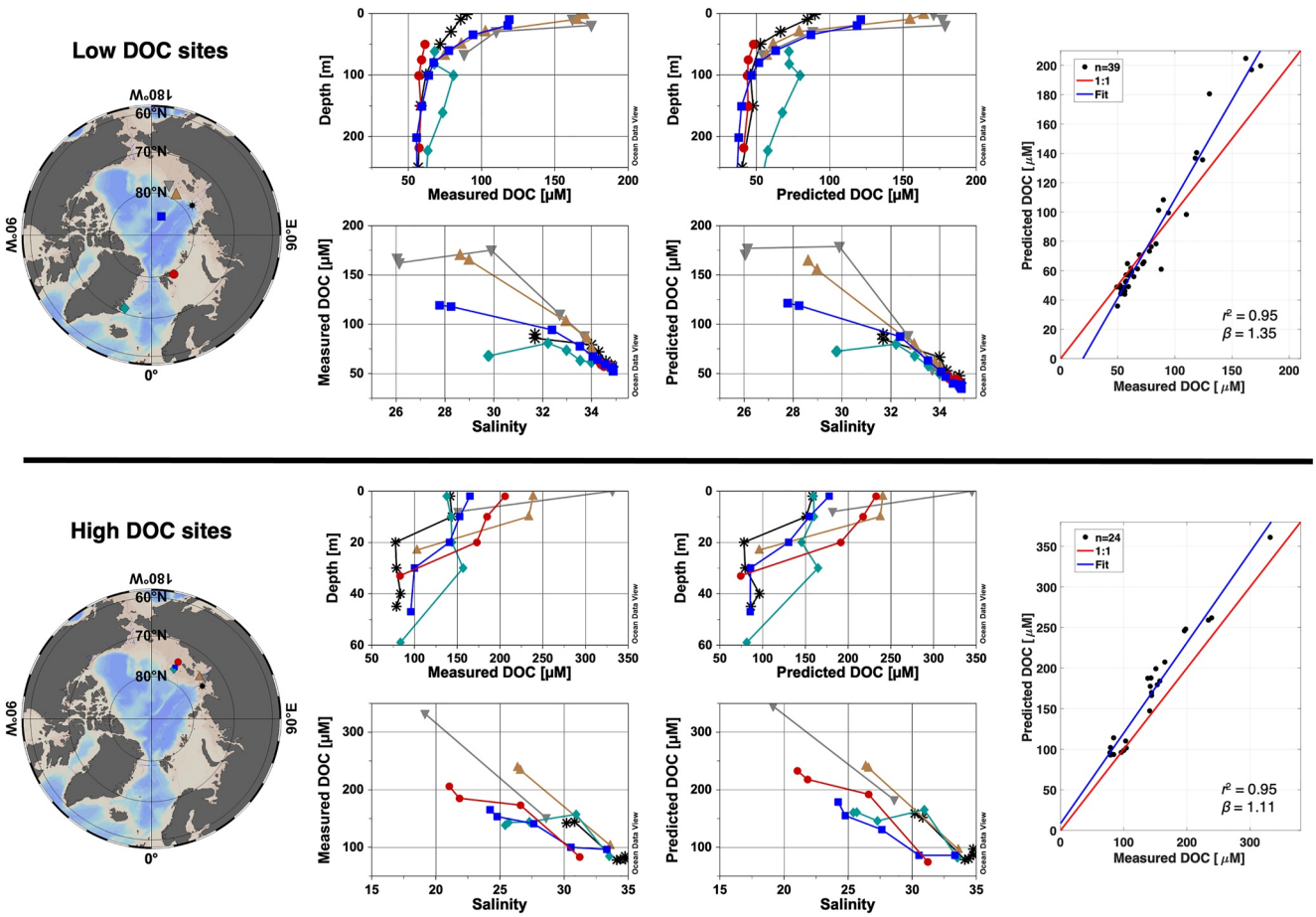

Figure 3. Selected profiles for measured (left) and predicted (center) dissolved organic carbon (DOC) (μM) at low (top panel) and high DOC sites (bottom panel): DOC profiles and DOC versus salinity plots. Scatter plots (right) show the correlation between measured (*x*-axis) versus predicted DOC (*y*-axis) for each respective group of selected stations. Red lines indicate the 1:1 line and the linear fit is presented as a blue line, whereas the r^2 and regression slope (β) for each plot are provided individually. Produced with Ocean Data View (Schlitzer, 2021).

Figure 3 shows that the estimates of DOC concentrations derived using the developed approach capture geographical and vertical gradients well. Examples of water column profiles and mixing plots in both low and high DOM waters are shown. At the selected low DOM stations there is a vertical gradient in DOM quality with surface waters influenced by terrestrial DOM and deeper waters with DOM of primarily marine origin. The salinity mixing plots indicate mixing of these two end members as well as a dilution due to sea ice melt contribution in surface waters. The algorithm is clearly capable of encompassing these gradients in DOM quality and quantity. For the selected stations in close proximity to riverine input the algorithm also performs well replicating the high DOC concentrations in plume and shelf waters.

We propose that the method presented here provides an opportunity to greatly expand coverage of DOC concentrations across diverse Arctic systems, spanning riverine, estuarine, coastal, and open ocean waters, and is capable of replicating geographical and vertical trends. This opens new opportunities for deriving high resolution DOC concentrations based on in situ spectroscopic measurements rather than water sampling, and this has the potential to greatly increase coverage of DOC concentrations in the remote and under-sampled Arctic waters. In particular the algorithm presented here holds promise for developing DOC estimates from in situ measurements using, for instance, spectroscopic nitrate sensors, which already measure UV absorption to quantify nitrate. These sensors are already designed for deployment on autonomous platforms such as moorings, tethered profilers and Argo floats. What is now needed is an assessment of the suitability of their design and performance for estimating DOC. It is not currently routine to save the spectral data collected by these sensors, but this potential should be harnessed in the future. This could provide a method suitable for high-resolution and long-term in situ monitoring

of DOC concentrations in aquatic systems, which are particularly relevant for remote regions undergoing considerable change such as the Arctic.

Data Availability Statement

The data on which this article is based are available in Fritz et al. (2023), Gonçalves-Araujo et al. (2015b, 2023a, 2023b), Granskog et al. (2020), Hansell (2017), Hansell et al. (2021), Hölemann et al. (2019a, 2019b, 2019c, 2019d), Hölemann et al. (2020), Juhls, Lizotte et al., 2019, Juhls, Overduin, Gonçalves-Araujo et al., 2019, Juhls, Overduin, Hölemann, et al., 2019, Juhls et al. (2020), Massicotte et al. (2017), Nishioka et al. (2020), Shiklomanov et al. (2018), and Tanaka et al. (2016).

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