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The supply and characteristics of colored dissolved organic matter (CDOM) in the Arctic Ocean: Pan Arctic trends and differences

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ABSTRACT

A comprehensive data set of dissolved organic carbon (DOC) and colored dissolved organic matter (CDOM) absorption measurements is analysed in light of tracing the supply and distribution of dissolved organic matter in the Arctic Ocean. Two years of river data from six major Arctic rivers (Kolyma, Lena, Ob, Mackenzie, Yenisei, and Yukon) and measurements from a transect across the Arctic Ocean are presented. The results show that although the Lena River currently dominates the supply of DOC and CDOM, climate change induced increases in base flow discharge will likely increase the contribution of the Yenisei River. Seasonal variations in the spectral characteristics of CDOM in the rivers reflected the shift in the dominant source of organic matter from modern plant litter in the spring freshet to older more degraded material during winter low flow periods. Strong correlations were found between the river loading of CDOM and DOC across the systems studied indicating that in situ CDOM sensors could be used in the future to improve estimates of riverine DOC loading. CDOM in the surface waters of the Eurasian Basin was largely characterised as riverine material although extrapolations to riverine end member concentrations suggested that approximately half the riverine CDOM is removed during its transport across the shelf. In contrast the Canadian Basin surface waters were characterised by a much greater proportion of autochthonous CDOM. These differences in DOM quality in the surface waters of the two basins are hypothesised to also influence the extent to which material is remineralised during its passage through the Arctic Ocean.

1. Introduction

The Arctic is currently greatly affected by climate change. Increasing surface air temperatures are altering the region's hydrological cycle (Peterson et al., 2002) and influencing the integrity of the permafrost (Osterkamp and Romanovsky, 1999; Guo et al., 2007; Walvoord and Striegl, 2007). These changes have a global significance with regard to climate and carbon cycling. Increased freshwater discharge will have consequences for water column structure and circulation in the Arctic Ocean and impact sea ice extent (Rudels et al., 2004). The subsequent export of freshwater to the North Atlantic will also influence the formation of North Atlantic Deep Water, which drives Atlantic meridional overturning circulation (Rahmstorf, 1995).

Climate warming in the Arctic will also have considerable effects on carbon cycling in the region. Soils in the northern circumpolar region represent a very large reservoir of organic carbon. They are estimated to contain 1672 Pg organic carbon which corresponds to approximately 50% of the global subterranean carbon pool (Tarnocai et al., 2009). The majority of this pool (88%) is estimated to be stored in perennially frozen soils (Tarnocai et al., 2009). Mobilisation of just a small portion of carbon stored in Arctic soils will have considerable impacts on the flux of organic carbon from land to the Arctic Ocean. For comparison, recent estimates of riverine flux of dissolved organic carbon are on the order of 25–36 Tg C yr^{-1} (Raymond et al., 2007). Gruber et al. (2004) estimated that climate induced permafrost disintegration during the next 100 yr, will release as much as 25% of carbon stored in Arctic soils. This has the potential to greatly influence riverine supply of DOC to the Arctic Ocean and subsequent export to the North Atlantic.

An increase in the riverine dissolved organic matter loading to the Arctic Ocean will have a series of effects on the physical, biological and chemical environment. A fraction of DOM is colored (CDOM) and absorbs ultra violet and visible light. Increased supply of CDOM by rivers will reduce the photic depth in the shelf regions in particular, resulting in continued light limitation even after sea ice retreat. In addition, reduced sea ice and higher concentrations of CDOM will lead to an increase in the importance of photochemistry (Osburn et al., 2009) for both direct remineralisation of terrestrial organic matter and production of labile organic material which can be utilized by microbes. The increased supply of labile organic carbon either directly via rivers (Holmes et al., 2008) or

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indirectly by photochemical degradation of refractory organic matter (e.g. Moran and Zepp, 1997) may also have a negative impact on primary productivity in the region, as heterotrophic bacteria out-compete phytoplankton for mineral nutrients (Thingstad et al., 2008).

Increases in CDOM supply by Arctic rivers can potentially alter the heat budget for the ice free coastal waters and hereby stratification and water column structure (Granskog et al., 2007). Currently it has been estimated that surface waters of the Arctic Ocean absorb as much as 30% more solar energy per unit area compared to other oceans, as a result of the high CDOM concentrations (Pegau, 2002). CDOM also greatly influences the remotely sensed water color measured by satellites and used extensively to estimate phytoplankton productivity (e.g. Arrigo et al., 2008). Before this can be taken into account the properties and distribution of CDOM in the Arctic need to be described. Currently there is a limited amount of data available on this. Here we present a study describing the seasonal variability in characteristics of CDOM in six major Arctic rivers and trace the mixing of CDOM across the Arctic Ocean. Our aim is to provide insight on sources of CDOM in surface waters (terrestrial/riverine or local autochthonous production) and hereby improve efforts to predict its distribution and refine remote sensing techniques.

2. Methods

River sampling was carried out in 2004 and 2005 as part of the PARTNERS project on six major Arctic rivers: Kolyma, Lena, Ob, Mackenzie, Yenisei, and Yukon (Fig. 1). Each river was sampled seven times per year. Additional details on sampling sites, dates, and methods can be found in Raymond et al. (2007) and Cooper et al. (2008). Briefly, water samples were taken using a depth integrated sampler (US D-96) at gauging stations according to USGS guidelines (McClelland et al., 2008). After collection, samples were filtered through pre-cleaned 0.45 μm capsule filters and frozen in polycarbonate bottles. All samples were stored frozen and shipped to the Department of Marine Sciences, Texas A&M University at Galveston, where the measurements for DOC and optical properties were made.

Samples from the Arctic Ocean were obtained during the 2005 Arctic Ocean Section Expedition with the Swedish icebreaker Oden. The cruise was in summer and sampled 53 stations along a transect from waters north of Barrow, Alaska across the Canada Basin to the Nansen Basin (Jones et al., 2008). A total of 289 samples were collected at depths ranging between 2 and 4354 m. Samples were collected from Niskin bottles mounted on a CTD rosette, filtered trough precombusted glass fiber filters (Whatman) into combusted glass ampoules and frozen until analyses.

CDOM absorbance was measured on a Shimadzu UV-2401PC/2501PC using a 5 cm quartz cuvette and Milli-Q water as a reference. Spectra were measured from 200 to 800 nm every 0.5 nm in triplicate then averaged. Absorbance measurements were transformed to absorption coefficients by multiplying by 2.303 and dividing by the path length (0.05 m). The shape of the absorption spectra between 300 and 650 nm was characterised by determining the exponential spectral slope coefficient (S) according to the approach by Stedmon et al. (2000). This wavelength range was chosen so that the data could

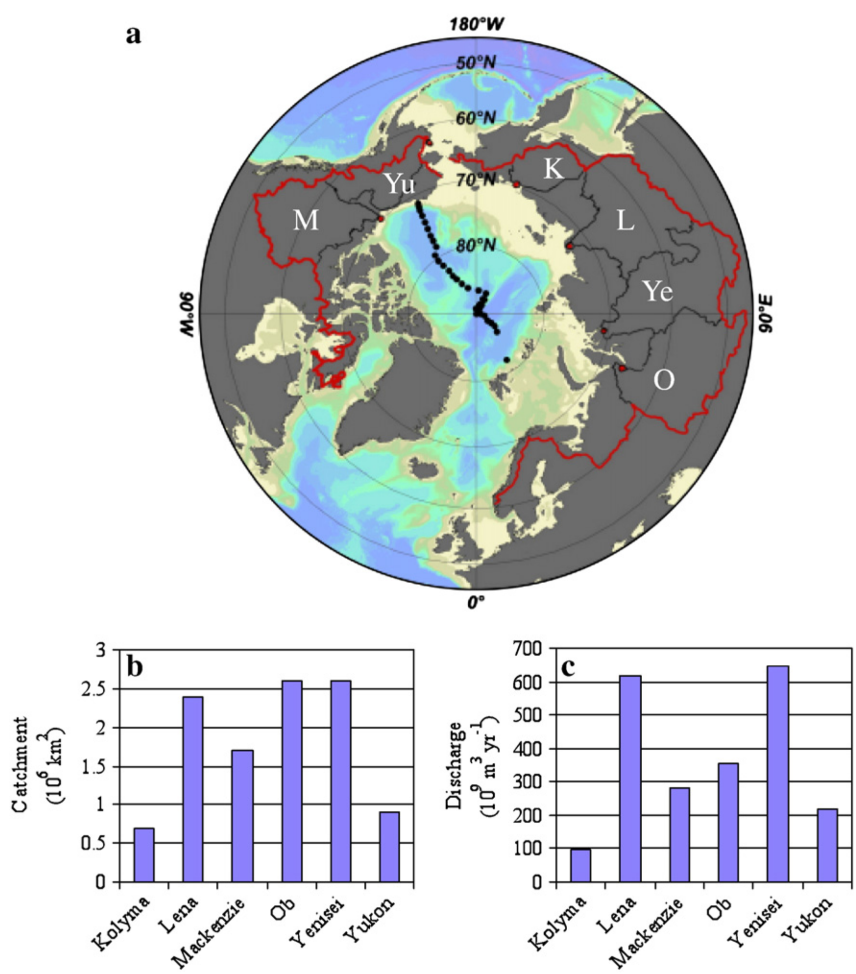

Fig. 1. a) Map of the Arctic Ocean and its river catchment (red line). Black line show the catchments of the individual rivers studied in the PARTNERS project. The black dots across the ocean represent the stations sampled during the AOS 2005 cruise. b) Catchment size and, c) annual discharge for the six rivers studied. Map was generated by Ocean Data View.