Oceanologia (2017) xxx, xxx—xxx

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.journals.elsevier.com/oceanologia/

ORIGINAL RESEARCH ARTICLE

Inherent optical properties and particulate matter distribution in summer season in waters of Hornsund and Kongsfjordenen, Spitsbergen

Sławomir Sagan *, **Mirosław Darecki**

Institute of Oceanology, Polish Academy of Sciences, Sopot, Poland

Received 23 July 2016; accepted 26 July 2017

KEYWORDS
Optical properties;
Particles;
Hornsund;
Kongsfjordenen

Summary Two Spitsbergen fjords, Hornsund and Kongsfjorden, are known for being under different hydrological regimes. The first is cold, separated from warm Atlantic water by East Spitsbergen Current, while Kongsfjorden is frequently penetrated by relatively warm Atlantic water. On the other hand, both are under strong influence of water discharge from glaciers and land freshwater input. During the period of observation in both fjords a dominant water mass was Surface Water, which originates mainly from glacial melt. The presence of suspended matter introduced with melt water in Surface Water is reflected by highest values of light attenuation and absorption coefficients recorded in areas close to glacier both in Hornsund and Kongsfjorden. In Hornsund the maximum light attenuation coefficient $c_{pg}(555)$ was 5.817 m^{-1} and coefficient of light absorption by particles $a_p(676) = 0.10\ \text{m}^{-1}$. In Kongsfjorden the corresponding values were 26.5 m^{-1} and 0.223 m^{-1}. In Kongsfjorden suspended matter of the size class 20—200 μm dominated over fractions smaller than 20 μm while in Hornsund dominating size fraction was 2—20 μm. The results provide an evidence of considerable range of variability of the optical properties mainly due to glacial and riverine runoff. The scale of variability of particulate matter in Kongsfjorden is bigger than in Hornsund. Most of the variability in Hornsund can be attributed to glaciers discharge and a presence of particles of mineral origin, while in Kongsfjorden the organic and mineral particles contribute almost equally to defining the optical properties of water.

---

* Corresponding author at: Powstańców Warszawy 55, 81-712 Sopot, Poland. Tel.: +48 587311811.
E-mail address: sagan@iopan.gda.pl (S. Sagan).

Peer review under the responsibility of Institute of Oceanology of the Polish Academy of Sciences.

ELSEVIER **Production and hosting by Elsevier**

http://dx.doi.org/10.1016/j.oceano.2017.07.006

Please cite this article in press as: Sagan, S., Darecki, M., Inherent optical properties and particulate matter distribution in summer season in waters of Hornsund and Kongsfjordenen, Spitsbergen. Oceanologia (2017), http://dx.doi.org/10.1016/j.oceano.2017.07.006

1. Introduction

In recent years Spitsbergen fjords have received special attention as potentially sensitive areas to ongoing climate change and global warming (Pavlov et al., 2013; Węsławski et al., 2017; Wlodarska-Kowalczuk and Weslawski, 2001). Observed ice retreat and intensified glacier melt (Muckenhuber et al., 2016), discharging particulate matter to the surrounding waters affect light penetration and its availability, thus changing underwater light climate for photosynthetic processes. Rising air temperatures increase the supply of fresh water to the fjords, which increases local stratification and reduce vertical mixing (Kohler et al., 2007; Mortensen et al., 2013). This may have an effect on underwater light distribution, if particulate matter locked in upper surface layer prevents light penetration into deeper layers (Pegau, 2002). Changes in quantity and type of sediment discharged by retreating glaciers may alter biological climate in fjords and may also be interpreted as another sign of long term warming processes. The changes are expected to be especially visible while comparing the areas of known contrasting hydrological regimes, as in the case of Hornsund and Kongsfjorden, Spitsbergen (Ormanczyk et al., 2017; Piwosz et al., 2009). The first is relatively cold, separated from warm Atlantic water by East Spitsbergen Current (Rudels et al., 2005), while the latter is easily but irregularly penetrated by relatively warm Atlantic water (Cottier et al., 2010; Inall et al., 2015).

The aim of the study is to examine the differences and similarities of the optical properties and characteristics of particulate suspensions in fjords waters in relation to water masses and locations of sampling — vicinity of the glaciers, possibly affected by glacial runoff, inner and outer fjord areas, thus along the expected gradient of change. The study aims to set up a baseline of optical properties that may be used as a reference for future observation or modeling of effects of climate warming.

2. Material and methods

The presented material was collected in 2009 between 22nd and 26th of July in Hornsund and 30th of July to 1st of August in Kongsfjorden; in 2010 between 22nd and 25th of July in Hornsund, and 30th to 31st of July in Kongsfjorden. In both campaigns sampling was performed in the same locations. Altogether 11 stations were visited in Hornsund and 9 stations in Kongsfjorden in 2009—2010 (Fig. 1). Stations were grouped according to their location in fjords: glacier stations (H1, HR3, B1, B2, KB5, MI2), inner stations in the middle of the fjords (H2, HR1, HR2, KB2, KB3) and outer stations, located at the entrance to the fjords (H4, Auk, KB1, KB0). The stations were sampled from the surface down to 110 m depth. Altogether 903 samples were collected in Kongsfjorden and 1002 samples in Hornsund.

Spectral light attenuation $c(\lambda)$ and absorption $a(\lambda)$ coefficients (inherent optical properties of water, IOP), salinity and temperature were measured in situ, with an instrument package consisting of an ac-9plus meter (WET Labs Inc., USA) and a Seabird SBE 49 FastCAT probe (Seabird Electronics, USA). Vertical sampling resolution was ~30 cm. Absorption a and beam attenuation c coefficients were measured at nine wavelengths; 412, 440, 488, 510, 532, 555, 650, 676 and 715 nm. Dynamic range of the meter is of 0.001—10.0 m^{-1}. Temperature and salinity corrections were applied to the signal, (Sullivan et al., 2006), as well as required correction for scattering (Zaneveld et al., 1994). The instrument was calibrated in ultrapure water and routinely checked for stability with air-readings. Every 3—6 casts all the optical elements of the sensors were routinely cleaned.

The light attenuation and absorption coefficients are linked by relation $c(\lambda) = a(\lambda) + b(\lambda)$, where $b(\lambda)$ is light scattering coefficient. Total absorption is a sum of absorption by pure water and water components, $a(\lambda) = a_w(\lambda) + a_p(\lambda) + a_g(\lambda)$, where index w denotes water, p — particles as a mixture of phytoplankton and non-pigmented particles, referred also as non-algal particles, *NAP*, and g, referred as *gelbstoff* — colored dissolved organic material (*CDOM*). Since ac-9plus meter is calibrated with pure water as a reference, output values of coefficients of absorption and attenuation do not account for the absorption or scattering by the water. Light absorption by dissolved organics and non-pigmented particles decay toward the red part of the light spectrum (Babin et al., 2003a; Bowers and Binding, 2006). In the investigated waters $a_g(676)$ and $a_{NAP}(676)$ may be considered negligible in case of the presence of phytoplankton, which absorbs light on 676 nm (Nima et al., 2016; Pavlov et al., 2015). In result, light absorption coefficient by particles $a_p(676)$ predominantly reflects the presence of the living organic.

Light scattering by particles, characterized by scattering coefficient $b_p(\lambda) = c_{pg}(\lambda) - a_{pg}(\lambda)$, depends on particles' size, shape, internal composition and origin — organic or mineral (Stramski et al., 2004). Light scattering in natural waters, which contain varying mixture of particles of different types and origin, is either weakly wavelength dependent (higher scattering in blue, lower in red) or spectrally neutral (Babin et al., 2003b). The contribution to scattering of organic particles, which have refraction index similar to that of surrounding water, is weaker than this of mineral particles. Model results suggest that all the planktonic components contribute to 17—20% of total scattering coefficient $b_p(\lambda)$ (Stramski et al., 2001). The value of $b_p(555)$ may be used as an indicator of a total particulate matter. The mid-spectrum wavelength of 555 nm is chosen to minimize dependency on type of particles and to avoid the effect of anomalous dispersion occurring around pigment absorption bands, (van de Hulst, 1957). Consequently, the ratio of $b_p(555)/a_p(676)$ was used as a proxy index of bulk particles composition where high/low ratio reflects the predomination of mineral/organic particles.

The particle volume concentration (PVC, microliter per liter [$\mu\text{L L}^{-1}$]) was measured with the Laser In Situ Scattering and Transmissometry (LISST), Sequoia Scientific, which was coupled with an optical probe. The instrument measures the light scattered by particles on 32 ring detectors arranged as to intercept light scattered at 32 different angles from a collimated laser beam (emission 670 nm) in 32 logarithmically spaced size classes ranging in diameter from 1.25 to 250 μm (Agrawal and Pottsmith, 2000). In this study, 32 discrete LISST size bins were grouped into three size classes. Without presumption about the actual origin of observed particles there was adopted classification proposed by Sieburth et al. (1978) for the separation of planktonic organisms into

Please cite this article in press as: Sagan, S., Darecki, M., Inherent optical properties and particulate matter distribution in summer season in waters of Hornsund and Kongsfjordenen, Spitsbergen. Oceanologia (2017), http://dx.doi.org/10.1016/j.oceano.2017.07.006