Science of the Total Environment 627 (2018) 579–585

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Dissolved organic carbon fractionation accelerates glacier-melting: A case study in the northern Tibetan Plateau

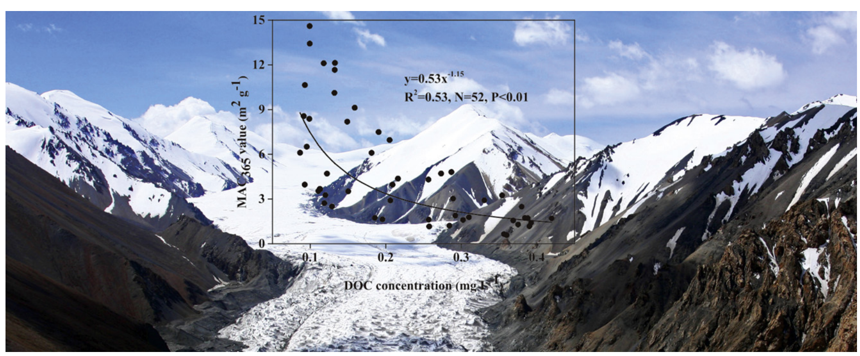
Zhaofu Hu [a,e], Shichang Kang [a,d,e,*], Fangping Yan [c], Yulan Zhang [a], Yang Li [b,c,e], Pengfei Chen [a], Xiang Qin [a], Kun Wang [a,e], Shaopeng Gao [b], Chaoliu Li [b,d,**]

[a] State Key Laboratory of Cryospheric Science, Northwest Institute of Eco-environment and Resources, Chinese Academy of Sciences, Lanzhou 730000, China
[b] Key Laboratory of Tibetan Environment Changes and Land Surface Processes, Institute of Tibetan Plateau Research, Chinese Academy of Sciences, Beijing 100085, China
[c] Laboratory of Green Chemistry, Lappeenranta University of Technology, Sammonkatu 12, Mikkeli 50130, Finland
[d] CAS Center for Excellence in Tibetan Plateau Earth Sciences, Chinese Academy of Sciences, Beijing 100101, China
[e] University of Chinese Academy of Sciences, Beijing 100039, China

HIGHLIGHTS

- Fractionation and RF change of DOC during the melting process were investigated.
- DOC with high MAC_{365} value was easy to keep in snow/ice during the melting process.
- DOC with high MAC_{365} value also had low wavelength dependence.
- RF caused by fresh snow DOC significantly increased during the melting process.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 20 December 2017
Received in revised form 25 January 2018
Accepted 25 January 2018
Available online xxxx

Editor: Xuexi Tie

Keywords:
Melting process
Dissolved organic carbon
Concentration
Light absorption characteristic
The Tibetan Plateau

ABSTRACT

In glacierized regions, melting process has a significant effect on concentrations and light absorption characteristics of dissolved organic carbon (DOC), potentially resulting in variations of its radiative forcing, which is not yet relevant research at glacier region of the Tibetan Plateau (TP). In this study, DOC fractionation and its radiative forcing change during the melting process were investigated at Laohugou glacier No. 12 (LHG glacier) in western Qilian Mts., northern TP. DOC concentrations in fresh snow, snowpit and surface ice samples were 0.38 ± 0.06, 0.22 ± 0.11 and 0.60 ± 0.21 mg L^{-1}, respectively. Their mass absorption cross-section at 365 nm (MAC_{365}) were 0.65 ± 0.16, 4.71 ± 3.68 and 1.44 ± 0.52 $m^2 g^{-1}$, respectively. The MAC_{365} values of snowpit samples showed a significant negative correlation with DOC concentrations, indicating DOC with high MAC_{365} values were likely to be kept in snow during the melting process. Topsoil samples of LHG glacierized region likely contributed a lot to snowpit DOC with high MAC_{365} values due to their similar absorption spectra. Spatially, the DOC concentration of surface ice samples increased from terminus to the upper part of the glacier. Correspondingly, the MAC_{365} value showed decreased trend. In the freezing experiment on surface ice and topsoil samples, small part of DOC with high MAC_{365} value was also likely to enter first frozen solid phase. In addition, the

* Correspondence to: S. Kang, State Key Laboratory of Cryospheric Science, Northwest Institute of Eco-environment and Resources, Chinese Academy of Sciences, Lanzhou 730000, China.
** Correspondence to: C. Li, Key Laboratory of Tibetan Environment Changes and Land Surface Processes, Institute of Tibetan Plateau Research, Chinese Academy of Sciences, Beijing 100085, China.
E-mail addresses: Shichang.kang@lzb.ac.cn (S. Kang), yulan.zhang@lzb.ac.cn (Y. Zhang), liy@itpcas.ac.cn (Y. Li), qinxiang@lzb.ac.cn (X. Qin), gaoshaopeng@itpcas.ac.cn (S. Gao), lichaoliu@itpcas.ac.cn (C. Li).

https://doi.org/10.1016/j.scitotenv.2018.01.265

radiative forcing caused by snowpit and surface ice DOC increased around 7.64 ± 2.93 and 4.95 ± 1.19 times relative to fresh snow DOC, indicating the snow/ice melting caused by increased light-absorbing DOC needs to be considered in the future research.

1. Introduction

As one of the largest snow and ice areas of the world, the Tibetan Plateau (TP) consists of approximately 36,800 glaciers with a total area and volume of 49,873 km^2 and 4561 km^3, respectively (Qin et al., 2017; Yao et al., 2007). At present, large part of TP glaciers are experiencing significant thinning and shrinkage at an accelerated rate (Barry, 2006; Berthier et al., 2007; Bolch et al., 2012; Kang et al., 2010; Yao et al., 2012), which is partly caused by increased deposition of light absorbing carbonaceous matters on glacier surface (X Li et al., 2017; Ming et al., 2012; Xu et al., 2009a). Numbers of studies have shown that carbonaceous matters deposited on the glacier surface caused albedo reduction of the surface snow/ice (Bond et al., 2013; Flanner et al., 2007; Hansen and Nazarenko, 2004; Jacobson, 2004; Ming et al., 2013; Qu et al., 2014; Xu et al., 2009b). Dissolved organic carbon (DOC) accounts for a large part of the carbonaceous matters at remote glacierized regions (Legrand et al., 2013; Li et al., 2016d; May et al., 2013). For instance, DOC accounts for approximately 29.37–52.94% of TC (total carbon) in snowpit samples of the TP (Li et al., 2016d).

Similar to other light-absorbing impurities, some components of DOC also absorb solar radiation. Normally, these constituents exhibit a brown appearance (Alexander et al., 2008) and are quantified by its ability to absorb sunlight in the UV and near-UV ranges. DOC has be characterized of important warming factor in aerosols (Bosch et al., 2014; Kirillova et al., 2014b; R Li et al., 2017; Martinsson et al., 2015; C Yan et al., 2015). For instance, the calculated ratios of solar energy absorbed by the water soluble organic carbon (WSOC) (the same as DOC) to black carbon (BC) in aerosols at the typical pollution area of North China (Kirillova et al., 2014a) and remote stations of the TP (Li et al., 2016c) were 2–10% and 6.03–11.41%, respectively. However, at present, although there are some related studies conducted on DOC of the TP glacierized regions (Feng et al., 2016; Li et al., 2016d; Xu et al., 2013; Yan et al., 2016), only one preliminary study calculated the radiative forcing caused by DOC relatively to that of BC in snowpit of a glacier located at northern TP (Yan et al., 2016), indicating that just like BC, light-absorbing DOC also caused glacier melting.

Whereas the result of above studies was limited because intensive fractionation occurred among different components of DOC during the melting process, causing the variations of light absorption ability of DOC (Meyer et al., 2009; Meyer and Wania, 2008; Muller et al., 2011; Xue et al., 2015). Previous studies have shown that those components of soil hydrophobic DOC with high light absorption ability were preferentially adsorbed by mineral dust during leaching process (Guo and Chorover, 2003; Peuravuori and Pihlaja, 1997; Salma et al., 2008). Consequently, snow hydrophobic DOC attached to particles (Meyer et al., 2009; Meyer and Wania, 2008) was likely to have high light absorption ability, potentially resulting in the variations of radiative forcing caused by DOC during the melting process. In addition, DOC strongly enriched in the early melt water samples during ice melting (Xue et al., 2016). Therefore, knowledges on the variations of DOC concentration and corresponding light absorption ability during the melting process of the TP glacierized regions are important for exact evaluation of its radiative forcing. However, to date, there is not yet relevant research in glacierized regions of the TP.

The mass absorption cross-section, usually measured at 365 nm (MAC_{365}) (Cheng et al., 2011; Kirillova et al., 2014a; Li et al., 2016c), is an important parameter for characterizing the light absorption properties of DOC (Cheng et al., 2011). Consequently, in this study, concentrations and MAC_{365} values of DOC of fresh snow, snowpit and surface ice at a typical glacier located at north TP (LHG glacier) were comprehensively investigated to study (1) the variations of concentration, light absorption characteristic and (2) radiative forcing of DOC during the melting process. Numbers of previous studies on DOC (Yan et al., 2016), cryoconite (Dong et al., 2016), mineral dust and BC (Li et al., 2016a; Y Li et al., 2016) at this glacier provide related useful information for this study.

2. Sampling and methods

2.1. Sampling sites

LHG glacier (39°24′–39°30′N, 96°29′–96°35′E, 4260–5481 m) is the largest mountain glacier (9.85 km, 20.4 km^2) at the northern slope of western Qilian Mountains (Dong et al., 2014; Du et al., 2008). The glacier is located in the northern TP and is surrounded by large sandy deserts and the Gobi desert (Fig. 1). It is considered as typical continental and arid climate characteristics (Zhang et al., 2012).

2.2. Sample collection

Four snowpits and one icepit were dug in the accumulation zone and the ablation area, respectively in August 2016 of LHG glacier (Fig. 1). In total, 46 snowpit and 8 icepit samples were collected from these pits followed our previous method (Yan et al., 2016) (Table S1). Meanwhile, 6 fresh snow samples were collected at glacier accumulation and ablation area. Later, 12 surface ice samples were collected along the eastern branch at an approximate elevation interval of 100 m from glacier terminus (4400 m) to the altitude of 4900 m. One snowpit was dug and 8 snowpit samples were collected at the elevation of 4550 m in November 2016. At the same time, 8 surface snow samples were collected at the elevation of 4300–4550 m (Fig. 1, Table S1). Two blanks were made for every sampling process to confirm that the contamination was low.

Because mineral dust is an important source of snow/ice DOC (Li et al., 2016d; Yan et al., 2016) at studied glacier, 8 topsoil samples of LHG glacierized region and 6 topsoil samples of non-glacierized region were collected from potential dust source regions of LHG glacier (Fig. 1) to investigate the fractionation of soil DOC during the leaching process, for the purpose of providing a better understanding of the influence of topsoil sourced DOC to snow/ice light-absorbing DOC.

2.3. Laboratory analyses

2.3.1. Concentration measurements for DOC

DOC concentrations were determined using a TOC-5000A analyzer (Shimadzu Corp, Kyoto, Japan) after the collected samples were filtered through a PTFE membrane filter with 0.45-μm pore size (Macherey–Nagel) (Yan et al., 2016). To study DOC characteristics of topsoil, the water-soil ratio of every topsoil sample was 10: 1 and the soil samples were soaked by ultrapure water for 24 h before being filtered. The detection limit of the analyzer, precision and average DOC concentration of the blanks were low of 0.015 mg L^{-1}, ±5% and 0.025 ± 0.006 mg L^{-1}, respectively, demonstrating that contamination during the pretreatment and analysis processing was weak.

2.3.2. Light absorption measurements

The light absorption spectra of DOC were measured between wavelength of 200 nm to 800 nm with 5 nm precision by a UV-Visible Spectrophotometer (SpectraMax M5, USA). Each spectrum was determined