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Spatiotemporal characterization of dissolved carbon for inland waters in semi-humid/semiarid region, China

K. S. Song[1,2], S. Y. Zang[3], Y. Zhao[1], J. Du[1], L. Li[2], N. N. Zhang[3], X. D. Wang[3], T. T. Shao[1], Y. Guan[3], and L. Liu[3]

[1]Northeast Institute of Geography and Agricultural Ecology, CAS, Changchun, China
[2]Department of Earth Sciences, Indiana University-Purdue University, Indianapolis, USA
[3]College of Geographical Science, Harbin Normal University, Harbin, China

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Correspondence to: K. S. Song (songks@neigae.ac.cn)

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Abstract

Spatiotemporal variations of dissolved organic carbon (DOC), inorganic carbon (DIC) in 26 waters across the semi-humid/semi-arid Songnen Plain, China were examined with data collected during 2008–2011. Fresh ($n = 14$) and brackish ($n = 12$) waters were grouped according to electrical conductivity (threshold = 1000 µS cm^{-1}). Significant differences in the mean DOC/DIC concentrations were observed between fresh (5.63 mg L^{-1}, 37.39 mg L^{-1}) and brackish waters (15.33 mg L^{-1}, 142.93 mg L^{-1}). Colored dissolved organic matter (CDOM) and DOC concentrations were mainly controlled by climatic-hydrologic conditions. The observation indicated that the outflow conditions in the semi-endorheic region had condensed effects on the dissolved carbon, resulting in close relationships between salinity vs. DOC ($R^2 = 0.66$), and vs. DIC ($R^2 = 0.94$). Independent data set collected in May 2012 also confirmed this finding (DOC: $R^2 = 0.79$), (DIC: $R^2 = 0.91$), highlighting the potential of quantifying DOC/DIC via salinity measurements for waters dispersed in the plain. Indices based on CDOM absorption spectra, e.g. DOC specific CDOM absorption ($SUVA_{254}$), absorption ratio $a_{250} : a_{365}$ ($E_{250:365}$) and spectral slope ratio (Sr, $S_{275-295}/S_{350-400}$), were applied to characterize DOM composition and quality. Our results indicate high molecular weight CDOM fractions are more abundant in fresh waters than brackish waters.

1 Introduction

Dissolved organic matter (DOM) is one of the largest bioactive reservoirs on the Earth's surface (Cole et al., 2007; Para et al., 2010). Though inland waters cover only a small fraction of the earth's surface but have a disproportional effect on the global carbon cycle (Cole et al., 1994, 2007; Tranvik et al., 2009; Armstrong, 2010). Inland waters play a vital role in burying, cycling and emitting carbon (Cole et al., 1994, 2007; Downing et al., 2008). Armstrong (2010) reported that a large amount of carbon taken up by terrestrial systems ends up in inland waters in the form of sediments, or is mineralized

HESSD

10, 6559–6597, 2013

Spatiotemporal characterization of dissolved carbon for inland waters

K. S. Song et al.

and released back into the atmosphere as CO_2 (Cole et al., 1994; Kosten et al., 2010). DOM, particularly its colored fraction (CDOM), influences light attenuation in waters (Vodacek et al., 1997; Zhang et al., 2007; Williamson and Rose, 2010; Stedmon et al., 2011), which affects the transport and bio-availability of materials such as trace metals and organic pollutants (Cory et al., 2006; Schlesinger et al., 2011; Ledesma et al., 2012). The mineralization of dissolved organic carbon (DOC), the major component of DOM, is a source of CO_2 in the atmosphere (Cole et al., 2007; Duarte et al., 2008; Spencer et al., 2009; Tranvik et al., 2009). DOC also serves to mediate the chemical environment through organic acids (Wetzel, 2001; Brooks and Lemon, 2007; Tranvik et al., 2009) and to enhance or alleviate the toxic forms of heavy metals, e.g. aluminum or mercury (Cory et al., 2006; Henneberry et al., 2011).

Temperature and precipitation are key factors influencing DOC mass balances and have important effects on DOC source, transport and fate (Larson et al., 2007; Jaffe et al., 2008; Fellman et al., 2011). Studies have indicated that concentrations of DOC in inland waters tend to decrease with increasing water residence times due to increased photobleaching and microbial activities (Curtis and Adams, 1995; Helms et al., 2008; Julian et al., 2008, 2011; Stedmon et al., 2011). Several investigations have also illustrated that CDOM is inversely associated with salinity in estuarine and near shore waters due to dominating riverine DOC inputs (Vodacek et al., 1997; Twardowski et al., 2004; Griffin et al., 2011). Inland waters in semi-arid to arid regions, however, generally tend to exhibit high salinity concentrations with elevated DOC concentrations (Brooks and Lemon, 2007). Curtis and Adams (1995) reported a positive correlation between DOC and specific conductivity in semi-arid east-central Alberta, Canada. However, this phenomenon, caused by evaporative concentration, has not been thoroughly investigated in other places (Wetzel, 2001; Brooks and Lemon, 2007). The role of saline water in DOC cycling merits further investigations for carbon cycling (Duarte et al., 2008).

The source and composition of DOM can be investigated through various analytical approaches (Summers et al., 1998; Baker and Spencer, 2004; Spencer et al., 2008). These methods primarily dependent on UV-visible (UV-Vis) and fluorescence

HESSD
10, 6559–6597, 2013

measurements have been widely used and reported in many investigations (Chin et al., 1994; Vodacek et al., 1997; Zhang et al., 2007, 2010; Stedmon et al., 2005, 2011; Helms et al., 2008; Fellman et al., 2011). Using the ratio of absorptions at 250 to 365 ($E_{250:365}$), De Han and De Boer (1987) successfully tracked changes in DOM molecule size, and the use of this ratio has been confirmed by other researchers (Peuravouri and Pihlaja, 1997; Zhang et al., 2007). The spectral slope (S) provides further information on CDOM origins, chemical processes and diagenesis, and the merits of the application of S are independent of CDOM concentration (Twardowski et al., 2004; Helms et al., 2008; Fichot and Benner, 2011). It has also been shown that S strongly correlates with fulvic acid molecular weight (Jaffe et al., 2008; Spencer et al., 2008, 2009, 2012). Recently, Helms et al. (2008) developed another index based on calculating the ratio of S value over two narrow wavelength ranges, i.e. the S of the shorter wavelength region (275–295 nm) to that of the longer wavelength region (350–400 nm). It is a dimensionless parameter called "slope ratio", here denoted as Sr. The effectiveness of this index has been demonstrated with CDOM samples from various waters, ranging from DOC rich wetlands to photobleached coastal waters and lakes over high altitude plateaus (Helms et al., 2008; Zhang et al., 2010). Further, it also has been modified to estimate DOC concentration using CDOM absorption features (Fichot and Benner, 2011; Spencer et al., 2012).

Dissolved inorganic carbon (DIC), largely composed of dissolved carbon dioxide and bicarbonate, is the primary source of carbon for photosynthesis and the generation of organic substances (Duarte et al., 2008). These inorganic compounds are generated by phytoplankton and higher plants in both lakes and rivers (Wetzel, 2001; Wilson and Xenopoulos, 2009), or they are generated externally in the drainage basin and imported to water bodies (Cole et al., 2007; Tranvik et al., 2009). The photobleaching process also produces DIC (Wetzel, 2001; Barros et al., 2011). Inorganic carbon is determined by the respiratory production of CO_2 by most organisms and by influxes of CO_2 and HCO_3^- from incoming water and from the atmosphere (Miller and Zepp, 1995; Wetzel, 2001; Lapierre and Giogio, 2012). DIC is a major constituent of inland waters

HESSD
10, 6559–6597, 2013

and can influence many characteristics of gaseous and nutrient availability and serves as the foundation of organic productivity. DIC constituents also influence water quality properties such as acidity, hardness and related characteristics (Wetzel, 2001). Thus, it is essential that the rudiments of DIC reactivity be evaluated (Tranvik et al., 2009; Song et al., 2011a).

The spatial and temporal variations of DOM in coastal and open oceans have been investigated widely (Vodacek et al., 1997; Babin et al., 2003; Stedmon et al., 2011). Comparatively, more uncertainties exist for DOM of inland waters in endorheic regions for its essential role in carbon cycling, e.g., the origin of DOM, conversion of DOC to DIC, and CO_2 outgassing from various inland waters (Cole et al., 2007; Sobek et al., 2007; Jaffe et al., 2008; Tranvik et al., 2009; Zhang et al., 2010). The spatiotemporal dynamics of dissolved carbon and its association with terrestrial inputs for inland aquatic ecosystems in semi-arid environments have only been investigated in a few regions (Brooks and Lemon, 2007; Mattsson et al., 2009; Fellman et al., 2011; Moore et al., 2011), further study is urgently needed for characterizing dissolved carbon for inland saline waters (Wetzel, 2001; Cole et al., 2007; Duarte et al., 2008; Tranvik et al., 2009), and quantifying the role of inland saline waters for carbon cycling (Cole et al., 2007; Duarte et al., 2008). DOC and DIC concentrations in inland waters are regulated by a combination of parameters that vary in both time and space within and across ecosystems and can be captured by the analysis of optical properties. The objectives of this study were: (1) to investigate the spatial characteristics of DOC and DIC in the semi-humid/semi-arid region; (2) to examine the seasonal characteristics of DOC and DIC; and (3) to perform a DOM source analysis using the relationship between optical absorption indices and salinity.

HESSD
10, 6559–6597, 2013

2 Materials and methods

2.1 Study area

The Songnen Plain is located in the central region of northeast China, covering an area of approximately 22.3×10^4 km^2 (42°49′–49°12′ N; 121°38′–128°30′ E, Fig. 1). It is a fluvial plain formed by the Songhua and Nenjiang rivers and their tributaries originating from the surrounding mountains, i.e. the Changbai (east), Small (north) and Great Xing'an (west) Mountain Ranges. Due to its geomorphology, many terminal-flow areas and temporary waters are formed, which result in several widely distributed fresh and saline water bodies in the plain. The plain is characterized by a temperate, semi-humid and semi-arid continental monsoon climate, with seasons alternating between dry and windy spring, humid and warm summer, windy and dry autumn and long, cold and dry winter (Zeng et al., 2011). The air temperature increases from north to south, spanning from 2 to 6 °C. The average annual precipitation ranges from 350 to 600 mm, with large inter- and intra-annual variations. More than 80 % of the total annual precipitation occurs during the growing season (from May to October). The potential evaporation exceeds 1300 mm yr^{-1}, resulting in water scarcity. Secondary salinization due agricultural practice increases river and lake water salinities (Wang et al., 2009). All together, 8988 lakes and reservoirs are distributed throughout the Songnen Plain, 1542 of them having areas greater than 100 ha, totaling 915 582 ha. These lakes in the Midwest of the plain were formed in a similar geological and climatic environment (Song et al., 2011b), and the waters tend to be brackish, particular these terminal waters with no out flow (Table 1) due to saline and alkaline soil erosion (Fig. 1a–c). Fourteen fresh (generally open water) waters and twelve brackish (terminal) waters were chosen for this study (threshold value = 1000 µS cm^{-1} was set to group fresh and brackish waters, Table 1). Note that Nanhu Lake (NHL) is located in Changchun City, some sewage outlets are connected with NHL.

HESSD
10, 6559–6597, 2013

2.2 Water sampling and quality determination

Twenty six water bodies were sampled from late August to early October 2011 for spatially characterizing dissolved carbon. Six field surveys were conducted across the Shitoukoumen Reservoir and Chagan Lake respectively to examine the seasonal characteristics during 2008–2011. Surface water samples were collected at each station approximately 0.5 m below the water surface, generally locating in the middle of water bodies. Water turbidity was determined using a Shangfen Vis-7230 spectrophotometer with a 3 cm quartz cell at room temperature ($20 \pm 2^{\circ}$) with Milli-Q water as reference. Salinity was measured through DDS-307 electrical conductivity (EC) meter with µS/cm (micro-Siemens/centimeter) units at room temperature ($20 \pm 2^{\circ}$) in the laboratory. Chlorophyll *a* (Chl *a*) concentration was determined using a Shimadzu UV-2050PC spectrophotometer (Song et al., 2011b). Total suspended matter (TSM) was determined gravimetrically, details can be found in Song et al. (2010). Total nitrogen (TN) was measured based on the absorption levels at 146 nm of water samples decomposed with alkaline potassium peroxydisulfate. Total phosphorus (TP) was determined using the molybdenum blue method after the samples were digested with potassium peroxydisulfate (APHA, 1998). To determine DOC concentrations, water samples were filtered through pre-combusted 0.45 µm GF/F filters. The standards for dissolved total carbon (DTC) were prepared from reagent grade potassium hydrogen phthalate in ultra-pure water, while DIC levels were determined using a mixture of anhydrous sodium carbonate and sodium hydrogen carbonate. DOC was calculated by subtracting DIC from DTC, both of which were measured by high-temperature catalytic oxidation (680 °C) using a Total Organic Carbon Analyzer (Shimadzu, TOC-VCPN). To validate the association between salinity and DOC/DIC, 153 independent samples across 26 water bodies were analyzed in May 2012.

HESSD
10, 6559–6597, 2013

2.3 CDOM laboratory analysis

In the laboratory, samples were filtered at a low pressure using pre-rinsed 25 mm Millipore membrane cellulose filter (0.22 µm). Absorption spectra were obtained between 200 and 800 nm at 1 nm increment using a Shimadzu UV-2550PC UV-Vis dual beam spectrophotometer through a 1 cm quartz cuvette. Milli-Q water was used as reference for CDOM absorption measurements. The absorption coefficient (a_{CDOM}) was calculated from the measured optical density (OD) of the sample using Eq. (1):

$$a_{\text{CDOM}}(\lambda) = 2.303[OD_{S(\lambda)} - OD_{(\text{null})}]/\gamma \tag{1}$$

where γ is the cuvette path length (0.01 m) and 2.303 is the conversion factor of base 10 to base e logarithms. Some fine particles may have remained in the filtered solutions and necessitated correction for scattering by fine particles. $OD_{(\text{null})}$ is the average optical density over 740–750 nm; therefore, the absorbance of CDOM was assumed to be zero. All absorption measurements were conducted within 48 h of field sampling. The CDOM absorption ratio index, $E_{250:365}$, was calculated using absorbance at 250 nm and 365 nm. The specific UV absorbance at 254 nm (SUVA_{254}) is defined as the absorbance at 254 nm (m^{-1}) divided by the DOC concentration (mg L^{-1}) (Weishaar et al., 2003).

2.4 Spectral slope (S)

A CDOM absorption spectrum, $a_{\text{CDOM}}(\lambda)$, can be expressed as an exponential function (Bricaud et al., 1995; Babin et al., 2003):

$$a_{\text{CDOM}}(\lambda_i) = a_{\text{CDOM}}(\lambda_r)\exp[-S(\lambda_i - \lambda_r)] \tag{2}$$

where $a_{\text{CDOM}}(\lambda_\text{i})$ is the CDOM absorption at a given wavelength λ_i, $a_{\text{CDOM}}(\lambda_\text{r})$ is the absorption estimate at the reference wavelength λ_r (440 nm) and S is the spectral slope. S is calculated by fitting the data to a nonlinear model over a wavelength range of 300

HESSD
10, 6559–6597, 2013

Spatiotemporal characterization of dissolved carbon for inland waters

K. S. Song et al.

to 500 nm, as suggested by Zepp and Schlotzhauer (1981) and Zhang et al. (2007). Different S values may result from using different curve-fitting approaches and spectral ranges (Babin et al., 2003; Binding et al., 2008; Astoreca et al., 2009). The ratio of S values at the shorter wavelength region (275–295 nm) and longer wavelength region (350–400 nm) were calculated (Sr) to determine CDOM sources (Helms et al., 2008).

3 Results

In all field surveys conducted over the 26 water bodies across the Songnen Plain, we encounter a large diversity of inland waters with varying water qualities. Most of the water bodies exhibit high TN concentrations (Mean ± SD, 3.25 ± 1.86 mg L^{-1}), and only two lakes contain average TN levels less than 1.0 mgL^{-1} (Table 2). Similarly, TP levels exhibit high variability, ranging from 0.06 to 1.86 mg L^{-1} (0.44 ± 0.52 mg L^{-1}). High Chl *a* concentrations (48.44 ± 39.71 µg L^{-1}) are observed in these waters. According to Carlson's trophic index (1977), 85 % of the water bodies is eutrophic or hypereutrophic (Zhang et al., 2010), and the remaining 15 % is mesotrophic. Agricultural non-point pollution is the main source of TN and TP for these waters, resulting in algal blooms in some of the waters (Wang et al., 2009; Song et al., 2011b). Due to regional hydrogeologic and climatic conditions, most waters in the western Songnen Plain have high salt contents and pH values. Overall, waters are highly turbid (87.0 ± 101.4 NTU), with high concentration of TSM (119.55 ± 131.37 mg L^{-1}) in the water column (Table 1). Strong winds in spring and autumn generally re-suspend the bottom sediments.

3.1 Dissolved carbon spatial characteristics

The DOC concentration in fresh waters ranged from 1.01 mg L^{-1} in Longhupao Lake (LHP) to 14.23 mg L^{-1} in Boluo Lake (BLL), large variation is observed within fresh waters (Fig. 2a). Likewise, large variation of DOC concentration is revealed in the brackish waters (Fig. 2b), which ranged from 3.6 mg L^{-1} in Nanyin Reservoir (NYR)

HESSD
10, 6559–6597, 2013

to 32.6 $mg\,L^{-1}$ in Zhongneipao (ZNP). Brackish waters exhibit higher DOC concentrations (16.4 ± 7.4 mg L^{-1}) than fresh waters ($5.6 \pm 2.4\,mg\,L^{-1}$), significant difference is observed between these two water types ($F = 232.4$, $p < 0.0001$, Fig. 3a). As shown in Fig. 2c, large variation is observed for DIC in fresh waters, in which the mean DIC concentration ranged from 16.2 $mg\,L^{-1}$ over Shitoukoumen Reservoir (STR) in east Plain, to 125.4 $mg\,L^{-1}$ in Huoshaohei (HSH) from west Songnen Plain (Fig. 1). Similarly, large variation of DIC concentration is observed in the brackish waters (Fig. 2d), ranging from 37.2 mgL^{-1} in Zhaojiatun (ZJT) to 482.4 $mg\,L^{-1}$ in Dongdahai (DDH). Fresh waters exhibit low DIC concentrations ($32.0 \pm 24.3\,mg\,L^{-1}$), while extremely high DIC concentrations are observed in brackish waters ($173.5 \pm 110.4\,mg\,L^{-1}$) (Fig. 2c,d), the average value is higher than that reported by Duarte et al. (2008). A significant difference for DIC is observed between brackish and fresh waters ($p < 0.0001$, Fig. 3b). Interestingly, fresh waters had relatively high mean DOC/DIC ratio (0.33 ± 0.13), while brackish water showed low mean ratio (0.21 ± 0.14). Similarly, significant differences for DOC and DIC are observed between open and terminal waters (Fig. 3a, b).

3.2 CDOM spatial characterization

The $SUVA_{254}$ varies widely in fresh waters (Fig. 4a), with low mean value ranges from 2.3 $L\,mg\,C^{-1}\,m^{-1}$ (±0.14 SD) in Nanhu Lake (NHL) to 8.7 $L\,mg\,C^{-1}\,m^{-1}$ (±2.8 SD) in Huoshaohei (HSH). Compared with the fresh waters, small range is observed for the $SUVA_{254}$ in the brackish waters (Fig. 4b), in which the mean value ranges from 2.8 $L\,mg\,C^{-1}\,m^{-1}$ (±0.06 SD) in the Chagan Lake (CGL) to 5.7 $L\,mg\,C^{-1}\,m^{-1}$ (±0.98 SD) in the Yuebingpao (YBP). Significant differences in $SUVA_{254}$ are observed between fresh and brackish waters (Fig. 5a, $p < 0.0001$). The averaged $SUVA_{254}$ is 5.8 $L\,mg\,C^{-1}\,m^{-1}$ (±1.72 SD) for fresh waters, which is much higher than that from brackish waters ($3.8 \pm 1.04\,L\,mg\,C^{-1}\,m^{-1}$).

The averaged $E_{250:365}$ values range from 5.5 (±1.46 SD) in Xinmiao Lake (XML) to 10.3 (±0.27 SD) in Huoshaohei (HSH) for fresh water (Fig. 4c). As shown in Fig. 4d,

HESSD
10, 6559–6597, 2013

comparatively larger ranges for $E_{250:365}$ are obtained for brackish waters, the averaged values range from 7.5 (±0.10 SD) in Kulipao (KLP) to 15.8 (±1.43 SD) in Xinmiao Lake (XML). Significant differences are observed for $E_{250:365}$ between fresh and brackish waters ($p < 0.0001$, Fig. 5b), suggesting that the high molecular size fractions of DOC are more abundant in fresh waters than that in saline waters in the Songnen Plain (Weishaar et al., 2003; Spencer et al., 2012).

The CDOM spectral slope ratio (*Sr*) obtained from various waters exhibit in Fig. 4e, f. Small averaged *Sr* value (0.803 ± 0.021) is observed from Daqing Reservoir (DQR), while the high value is recorded in the Nanhu Lake (1.46 ± 0.046 SD) for fresh waters (Fig. 4c). Note that smallest SUVA 254 is observed in Nanhu Lake, while the highest *Sr* value is found in the same lake. As shown in Fig. 4f, comparatively larger ranges for *Sr* are obtained for brackish waters, the averaged values range from 1.32 (±0.006 SD) in Kulipao (KLP) to 2.1 (±0.123 SD) in Xidahai Lake (XDH). The fresh and brackish waters exhibit obvious difference for *Sr* values (Fig. 5c, $p < 0.0001$), in which the averaged *Sr* values are 1.09 ± 0.17 and 1.41 ± 0.32 for fresh and brackish waters, respectively. This finding is consistent with the results from Spencer et al. (2008, 2012) and Helm et al. (2008), showing water with long residence time tend to exhibit higher *Sr* values.

3.3 Seasonal variation

3.3.1 Dissolved carbon

The water quality characteristics in both STR and CGL are shown in Table 3. Apparently seasonal variations for TN, TP, Chl *a* and TSM concentration are observed in both waters. Higher concentrations of salinity, pH, and CDOM absorption in the CGL are observed than that in the STR (Table 3). The DOC in waters shows seasonal dynamics due to hydrological, climatic and landscape variation (Jaffe et al., 2008; Spencer et al., 2008, 2012). As shown in Fig. 6a, the STR shows much lower DOC in the growing season than the CGL. High DOC concentrations are observed in both the STR and CGL in May, mainly due to snowmelt discharge. The similar findings have been reported in

HESSD
10, 6559–6597, 2013

streams in Sweden (Ågren et al., 2007, 2010), in water in across USA (Jaffe et al., 2008; Helms et al., 2008), and catchments that drain to the Arctic Ocean (Neff et al., 2006; Spencer et al., 2008). Decreased DOC concentrations are observed from May to October in the STR (Fig. 6a). In contrast, higher DOC concentrations are revealed in the May and October, while lower values are observed in July, August and September in the CGL (Fig. 6a).

As illustrated in Fig. 6b, the overall DIC concentration in the CGL is significantly higher than that from the STR ($F = 337.2$, $p < 0.0001$). Higher DIC is observed in May for the STR, which is consistent with the DOC concentration illustrated in Fig. 6a. Accordingly, a higher variation is observed in May, while small variation values are shown for the other months. The CGL shows high DIC concentrations with less seasonality, except for June and August (Fig. 46b). The samples in June and August reveal a relatively larger variation, particularly small variations are observed in September and October.

3.3.2 CDOM temporal characterization

As illustrated in Table 3, the CGL exhibits significantly higher $a_{\mathrm{CDOM}}(355)$ values ($17.5 \pm 12.03\,\mathrm{m}^{-1}$) than the STR ($5.6 \pm 0.72\,\mathrm{m}^{-1}$; $p < 0.003$). Likewise, significant differences are found for $a_{\mathrm{CDOM}}(440)$ values between the CGL and STR ($p < 0.001$). As shown in Fig. 7a, the STR and CGL exhibit higher SUVA_{254} values in May. The SUVA_{254} values in the STR show the pattern observed for DOC concentration sampled in the growing season (see Fig. 6a). As detailed above, snowmelt runoff generally carries more high molecular weight DOC from various landscapes after the thaw in spring (Ågren et al., 2007), resulting in higher SUVA_{254} values in May. Except in May, the SUVA_{254} values in the CGL show less variation (Fig. 7a). Overall, significant difference of SUVA_{254} between fresh and brackish waters during ice-free season is observed ($p < 0.0001$, Fig. 8a)

HESSD
10, 6559–6597, 2013

Overall, $E_{250:365}$ increases from May to October in the CGL (Fig. 7b). However, stable $E_{250:365}$ values are observed for the STR, except in May. Low $E_{250:365}$ values are observed in May and June, which is most probably due to snow melt in the spring. An overall increased *Sr* values are observed in the STR and the CGL (Fig. 7c). Through comparison, it can be seen that the *Sr* values follow the similar trends as shown in $E_{250:365}$ for both the STR and CGL, while inverse trend is observed for the $SUVA_{254}$ values. Although significant difference of $E_{250:365}$ is revealed between fresh and brackish waters (Fig. 8b), the difference is not as significant as that demonstrated in *Sr* (Fig. 8c) and SUVA $_{254}$ (Fig. 8a).

3.4 Dissolved carbon versus salinity

As stated above, higher DOC and DIC concentrations are observed in brackish waters in the Songnen Plain. The waters generally exhibited high salinity concentrations due to the terminal aquatic environments, representing terminal points for carbon flow in the terrestrial landscape (Duarte et al., 2008). Regression analyses between salinity and dissolved carbon parameters were conducted on samples from 26 water bodies collected in August to September 2011 (Fig. 9). The concentrations of DOC in various waters increased with increasing salinity (Fig. 9a; $R^2 = 0.66$, $p < 0.001$). Likewise, linear relationship between DIC and salinity is observed (Fig. 9b; $R^2 = 0.94$, $p < 0.0001$). To test the stability of the relationship, DOC vs. salinity from independent samples in May 2012 were demonstrated in Fig. 9c ($R^2 = 0.96$, $p < 0.0001$). Excluding four samples with extremely high values (from XDH, see Fig. 1b), it still obtained high regression determination coefficient ($y = 67.25x + 11.216$; $R^2 = 0.79$, $p < 0.0001$). Similarly, high correlation between DIC and salinity was observed (Fig. 9d; $R^2 = 0.98$, $p < 0.0001$). High R^2 value was obtained between DIC and salinity ($y = 194.74x + 9.66$; $R^2 = 0.91$, $p < 0.0001$) when four samples with extremely high values were excluded.

HESSD
10, 6559–6597, 2013

4 Discussion

4.1 Spatial variation

In our case study, substantial variations for both DOC and DIC values are observed between fresh and brackish waters in the Songnen Plain. The pattern is similar as that reported by Curtis and Adams (1995) for lakes in east-central Alberta in the semi-arid region of Canada. Seasonally averaged DOC concentrations in brackish waters are much higher than in fresh water bodies, indicating that DOC concentration violates the trend in humid regions, with DOC decreasing with water residence time due to prolonged photobleaching and possible dilution (Twardowski and Donaghay, 2002; Julian et al., 2011; Spencer et al., 2009, 2012). The findings indicate that regional hydrogeologic and climatic conditions play an important role in DOC variability (Sobek et al., 2007; Duarte et al., 2008; Jaffe et al., 2008). The terminal waters accumulate DOC via runoff passing through various landscapes (Larson et al., 2007; Song et al., 2011a). DOC is lost from terminal water bodies through sinking to the bottom as sediment (Cole et al., 2007; Tranvik et al., 2009; Barros et al., 2011) or being transformed into DIC (includes CO_2) in the water column (Brooks and Lemon, 2007; Duarte et al., 2008; Tranvik et al., 2009). Consequently, DOC and DIC accumulate in brackish (terminal) waters at much higher rates for these in fresh (open) waters (Brooks and Lemon, 2007; Duarte et al., 2008).

In particular, average DIC values in brackish waters in the western Songnen Plain are much higher than in fresh waters in the southeastern part of the plain, i.e. the Erlong Lake (ELL) and the STR. Comparatively shorter sunlight durations (Zeng et al., 2011) and water residence times (Wang and Dou, 1998) result in lower DIC production and accumulation in fresh waters (Fig. 1d). DIC concentrations also exhibit larger variations in the brackish waters. As noted above, most of the waters in the western Songnen Plain exhibit the limnetic characteristics of shallow plain lakes, and stronger wind generally re-suspends the loose bottom sediment (see Table 2 for the KuliPao Lake, Nanyin Reservoir and Cuibaguzi Lake). Longer sunlight durations in western part of

HESSD
10, 6559–6597, 2013

the Songnen Plain may also cause higher DIC concentrations due to enhanced photochemical oxidation processes (Brook and Lemon, 2007; Tobias and Bohlke, 2011), speeding up the mineralization of DOC in these waters (Granéli et al., 1996; Duarte et al., 2008). Other factor, i.e. land use (Wilson and Xenopoulos, 2008; Yallop and Clutterbuck, 2009; Philips, 2010), may play an important role in the higher DIC levels in these terminal waters is the saline-alkaline soil properties around these water bodies (Fig. 1b–c) (Wetzel, 2001; Duarte et al., 2008).

Various indices have been applied to characterize DOC (CDOM) in the Songnen Plain, in which $SUVA_{254}$ is proven to be effective index for characterizing DOC concentrations. The $SUVA_{254}$ reveals that high molecular weight DOC fractions are abundant in fresh waters due to quick exchange rates of DOC in the water column and less residence time (Spencer et al., 2008, 2012). The brackish (terminal) waters have longer residence times (Table 1). Thus, DOC concentrations increased, even though limited inflow led to decreased DOC transportation compared to humid or semi-humid regions (Duarte et al., 2008). These findings suggest that some DOC inputs can be evapo-concentrated (Curtis and Adams, 1995). It is also possible that internal sources of DOC exceed DOC transformation, sinking and outgassing rates with increased salinity (Cole et al., 2007; Tranvik et al., 2009; Lapierre and Giogio, 2012). Despite prolonged photo-oxidation or autochthonous DOC origins, the lower molecular weight DOC fraction is more abundant in brackish (terminal) waters. Thus, lower $SUVA_{254}$ values are observed in brackish (terminal) waters.

Higher value for both $E_{250:365}$ and *Sr* are observed in brackish (terminal) waters in the Songnen Plain. As briefly mentioned above, various factors regulate the DOC flux for inland waters both in time and space, but dominating factors may vary spatiotemporally (Jaffe et al., 2008; Spencer et al., 2009, 2012; Zhang et al., 2010; Fellman et al., 2011). Nevertheless, the $E_{250:365}$ and *Sr* values are found to be useful for indicating seasonal DOC compositional variations. It is also confirmed that $E_{250:365}$ and *Sr* are effective proxies for investigating DOC composition (Fichot and Benner, 2011). Relatively short residence times in open waters enhanced terrestrial DOC input, resulting

HESSD
10, 6559–6597, 2013

in high molecular weight DOC fractions (Fig. 4c–f). In contrast, longer irradiation times in the Midwest Songnen Plain generally decreased the high molecular weight fraction (Towdowski et al., 2002; Helms et al., 2008). Note that the special behavior of $SUVA_{254}$, $E_{250:365}$ and *Sr* in Nanhu Lake is most likely due to the sewage water has different DOM composition, which ultimately shows different CDOM characteristics with respect to other fresh waters.

To further analyze the climatic variables influence on dissolved organic carbon in waters across the Songnen Plain, multiple linear regression analysis were performed on both DOC and DIC using precipitation (*P*), potential evaporation (ET_0, calculated based on FAO-Penman-Monteith Equation), and sunshine duration hours (S) as independent variables. As expected, the ET_0 has larger impact on DOC with respect to precipitation and sunshine duration hours (see slope value for ET_0 in Table 4). The potential evaporation representing the water output for terminal waters results in the condensed effect on DOC concentration. In contrast, an inverse trend was observed between DIC and climatic variables (Table 4). The observation indicates that climatic variables exerted significant impact on DOC and DIC concentration in the Songnen Plain. However, the outflow condition is another critical factor that influences the DOC and DIC spatial pattern markedly (Fig. 3a, b). So far, our explanation is that sunshine duration may enhance photobleaching that could speed up DOC conversion to DIC (Graneli et al., 1996; Wetzel, 2001; Lapierre et al., 2012). Further investigation need to be carried out to examine the underlying reason.

4.2 Seasonal variation

As mentioned above, the higher DOC concentrations in both the STR and CGL in May are due winter accumulated dissolved carbon in soil flushed into stream or lakes during the snow melt season in cold temperate zone (Ågren et al., 2007; Song et al., 2011a). The DOC concentration in fresh waters in the ice-free season can be very variable, depending on the hydrological and climatic condition, and landscape in the catchment (Wetzel, 2001; Jaffe et al., 2008; Spencer et al., 2012). However, lower DOC is

HESSD
10, 6559–6597, 2013

generally expected in fresh waters during low flow season due to limited allochthonous input. Decreased autochthonous origin due to low algal abundance resulting from temperature in the STR could be another reason for the relative low DOC concentration in October (Fig. 6a). The high DOC concentrations for the CGL in autumn are probably due to evaporation exceeds inflow resulting in condensed DOC concentration. In summer season (July, August and September), more recipient water from precipitation and runoff diluted DOC in the water is the main reason for the lower DOC concentration (Fig. 6a).

High molecular weight DOC is more abundant in the early stages of the growing season (May) in the Songen Plain, larger molecular weight CDOM prevailed in the spring with snow melt as reported by Ågren et al. (2007, 2010). Overall, the STR shows higher $SUVA_{254}$ values than the Chagan Lake due to its more terrestrial DOM inputs and less residence time (Hood et al., 2003). Larger DOC variation and higher CDOM absorption values are observed in the STR, which is confirmed by samples collected in May (Fig. 7a). Note that overall patterns show larger molecular CDOM are dominated in fresh waters, different indices, e.g. the $SUVA_{254}$, $E_{250:365}$ and Sr demonstrate variations for CDOM characterizing in different seasons for both fresh and brackish waters (Fig. 8a–c). The underlying reason is probably due to the seasonal variation and major sources of CDOM concentration and compositional fractions (Spencer et al., 2012), particularly after punctuated discharge events coming from different land use/land covers, which are consistent with investigations by Wilson and Xenopoulos (2008, 2009), and Yallop and Clutterbuck (2009). Variations observed in the summer are most likely due to the variations in discharge and phytoplankton abundance during the wet and warm season.

4.3 Dissolved carbon vs. salinity

Within semi-humid and semi-arid regions, dissolved carbon is related to salinity, reflecting water residence times and dissolved matter accumulation (Duarte et al., 2008; Mattsson et al., 2009). This relationship implies that source and sink patterns are similar among lakes within semi-arid regions (Cole et al., 1994; Duarte et al., 2008). The most likely explanation is that the most resilient DOM is evapo-concentrated in the semi-arid region, and not outlet for accumulated carbon for these inland waters in the endorheic watershed. The relationship of DIC and salinity is more consistent (Fig. 9b, d), while the slope and intercept for DOC and salinity regression model are varied (Fig. 9a, c). Comparatively, DIC is more stable, which explains the stable relationship between DIC and salinity (Lapierre and Giorgio, 2012). An empirical model can be calibrated with larger dataset for estimating DIC for inland waters in the Songnen Plain. However, DOC is more labile (photochemical and microbial degradation) with different source (allochthonous/autochthonous) and composition (Spencer et al., 2009, 2012), resulting in different relationship between DOC and salinity. With model calibration with data sets collected in various season, it is also possible to estimate DOC concentration in the Songnen Plain due to the high variance it can explain ($R^2 > 0.6$).

4.4 Future implications

The ability to derive DIC concentration via salinity in the Songnen Plain has potential implications for improving carbon storage estimates in the semi-arid regions. To quantify the carbon cycling role for inland waters, calculation of the flux of dissolved carbon for inland waters is dependent on accurately constraining the concentration and volume of water bodies (Cole et al., 1994, 2007; Duarte et al., 2008; Tranvik et al., 2009). Thereby any technique that can improve flux estimates is of assistance in improving freshwater and brackish water delineation and DIC estimates. Recent studies have realized the limitation for quantifying carbon flux of brackish inland waters (Cole et al., 2007; Duarte et al., 2008; Tranvik et al., 2009; Spencer et al., 2009, 2012). The correlation between DIC and salinity from the Songnen Plain enhances the ability to easily increase spatiotemporal resolution through quick in situ data collection. If such an approach across other watersheds with similar environmental conditions holds true, it will lead to a quick estimates of dissolved carbon storage combined with remote sensing technology (Cole et al., 2007; Tranvik et al., 2009) for providing water surface

HESSD
10, 6559–6597, 2013

area, and possible volume (Hendriks et al., 2012). However, this relationship generally varies due to source of CDOM and DOC, photochemical process (Spencer et al., 2009, 2012). Coupled with remote sensing, it provides potential for DOC storage estimates (Griffin et al., 2011).

5 Conclusions

The knowledge of DOC and DIC in terminal (brackish) inland waters is rare and incomplete, however it plays an important role for carbon cycling in saline (includes brackish) inland waters. A comprehensive study is require for an understanding of dissolved carbon characteristics that facilitate carbon cycling estimates for inland waters, particularly terminal waters in semi-arid or arid regions. For the first time, the spatial and temporal characteristics of DOC and DIC in fresh (open) and brackish (terminal) water bodies in the Songnen Plain, China, were investigated, which gains knowledge on dissolved carbon characteristic for brackish inland waters. This study provides insight into carbon cycles linked to hydro-climatic conditions in semi-arid inland waters. We concluded that: (1) compared to open waters in the southeast of Songnen Plain, higher DOC and DIC concentrations are observed in brackish (terminal) waters in the western part of the plain; (2) terminal aquatic environments result in elevated DOC and DIC concentration, and significant correlations are observed between salinity-DOC and salinity-DIC, which provides potential for dissolved carbon estimates through salinity; (3) relatively high molecular weight DOC fractions are more abundant in fresh waters. The elevated DOC and DIC levels in the semi-arid Songnen Plain might inspire further investigation for understanding the carbon cycling process in terminal inland aquatic ecosystems, which is only addressed limitedly for saline (including brackish) inland waters across the world. Particular attention should be focused on the partial pressure of CO_2 (pCO_2) in these brackish waters for the ongoing works.

HESSD
10, 6559–6597, 2013

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HESSD
10, 6559–6597, 2013

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HESSD
10, 6559–6597, 2013

Spatiotemporal characterization of dissolved carbon for inland waters

K. S. Song et al.

Title Page
Abstract | Introduction
Conclusions | References
Tables | Figures
◀| |▶
◀ ▶
Back | Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

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HESSD
10, 6559–6597, 2013

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HESSD
10, 6559–6597, 2013

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HESSD
10, 6559–6597, 2013

Spatiotemporal characterization of dissolved carbon for inland waters

K. S. Song et al.

Table 1. Lake (or reservoir) names, abbreviation (with numbers), sampling dates, mean water surface area, water volume, water depth, inflow and outflow conditions, pH value and salinity for waters across the Songnen Plain.

Lake Name	Abbreviation (Number)	Date	Area (km^2)	Volume ($10^8 m$)	Depth (m)	In-F[1]	Out-F[2]	pH	Salinity (PSU)
Nanhu	NHL (1)	26 Sep 11	1.0	0.03	3.7	SW + R	Y	8.28	0.15
Erlonghu	ELL (2)	19 Sep 11	89.5	1.76	11.6	R + P	Y	8.23	0.16
Xinlicheng	XLC (3)	20 Sep 11	58.5	5.92	7.6	R + P	Y	8.57	0.14
Shitoukoumen	STR (4)	08–10*	73.3	3.86	7.5	R + P	Y	8.09	0.13
Xinmiao	XML (5)	30 Aug 11	31.6	0.62	2.1	C + P	Y	9.12	0.46
Yueliang	YLL (6)	1 Sep 11	206.1	4.74	3.6	R + P	Y	7.93	0.10
Daqing	DQR (7)	8 Sep 11	56.1	1.03	1.3	C + P	Y	8.14	0.10
Hongqi	HQR (8)	9 Sep 11	26.2	0.83	2.8	C + P	Y	8.36	0.11
Lamasi	LMS (9)	24 Sep 11	51.0	1.52	3.0	P	Y	8.46	0.09
Dongsheng	DSR (10)	25 Sep 11	7.8	0.31	3.2	C + P	Y	8.05	0.11
Longhupao	LHP (11)	23 Sep 11	130.8	1.75	2.7	R + P	Y	8.09	0.37
Yuebingpao	YBP (12)	22 Sep 11	23.0	0.57	2.5	P	N	8.92	0.54 +
Yueliangpao	YLP (13)	7 Sep 11	1.1	0.07	1.5	R + P	N	7.78	0.52 +
Chagan	CGL (14)	08–11*	375.2	6.42	2.2	C + P	N	9.12	0.57 +
Talahong	TLR (15)	16 Sep 11	71.6	1.89	1.8	R + P	Y	8.64	0.24
Boluohu	BLL (16)	25 Aug 11	49.3	0.90	1.3	R + P	Y	8.60	0.25
Zhongneipao	ZNP (17)	10 Sep 11	13.6	0.55	1.7	C + P	N	9.09	0.65 +
Zhaojiatun	ZJT (18)	8 Sep 11	5.6	0.17	0.7	P	N	8.42	0.68 +
Qingkenpao	QKP (19)	11 Sep 11	33.1	0.73	1.0	C + P	N	9.33	1.51 +
Xinhuahu	XHL (20)	14 Sep 11	7.4	0.18	1.3	P	N	9.33	1.25 +
Dongdahai	DDH (21)	14 Sep 11	16.5	0.25	0.4	P	N	8.91	0.66 +
Xidahai	XDH (22)	14 Sep 11	12.5	0.46	1.6	P	N	8.97	0.49 +
Kulipao	KLP (23)	15 Sep 11	33.7	0.71	2.1	R + P	N	9.27	1.42 +
Nanyin	NYR (24)	15 Sep 11	47.1	1.05	2.1	C + P	N	9.17	0.95 +
Huoshaohei	HSH (25)	17 Sep 11	73.4	1.92	2.5	P	Y	9.28	0.73 +
Cuibaguzi	CBG (26)	25 Sep 11	58.4	1.12	1.4	P	N	9.35	0.71 +

Notes: 1 denotes the major inflow type, R = river, C = channel, P = precipitation, SW = sewage; 2 denotes the out flow type, Y = yes, N = no; * indicates that multiple field campaigns were conducted across these waters; + indicates brackish waters.

HESSD
10, 6559–6597, 2013

Table 2. Mean values of water-quality parameters and CDOM absorption grouped as: all sites (all), non-outflow waters (NOF), and outflow waters (OF) during late August to late September. TN and TP denote total nitrogen and total phosphorus, respectively; Chl *a* denotes chlorophyll *a* concentration, TSM denotes total suspended matter, and Turb denotes water turbidity, – indicates no data available.

Lake Abbreviation	TN ($mg L^{-1}$)	TP ($mg L^{-1}$)	Chl *a* ($ug L^{-1}$)	TSM ($mg L^{-1}$)	Turb (NTU)	$a_{CDOM}(355)$ (m^{-1})	$a_{CDOM}(440)$ (m^{-1})	*N*
NHL	2.15	0.14	20.2	80.4	10.3	8.66	2.53	8
ELL	1.94	0.13	60.7	14.0	7.3	3.45	0.96	21
XLC	0.89	0.06	14.3	8.1	10.7	3.08	0.82	20
STR	1.60	0.06	23.4	35.7	37.8	2.88	0.77	15
XML	–	–	28.5	80.8	21.2	9.04	2.84	10
YLL	9.77	1.86	55.7	44.0	51.4	25.45	10.39	20
DQR	2.08	0.07	11.7	40.2	37.6	5.69	1.48	5
HQR	5.28	1.01	18.1	17.7	24.3	7.56	1.57	3
LMS	0.96	0.02	17.6	39.9	52.1	5.04	1.46	5
DSR	5.40	1.72	136.4	44.6	22.4	16.91	4.25	5
LHP	3.50	0.48	59.9	258.9	64.5	26.32	10.65	10
YBP	2.41	0.20	43.1	63.3	149.6	3.64	0.52	3
YLP	2.51	0.57	9.4	29.5	23.9	11.17	2.30	3
CGL	2.78	0.43	46.3	65.7	88.5	8.37	1.69	15
TLR	4.42	1.21	52.0	554.6	97.2	11.90	3.06	4
BLL	4.37	1.13	48.5	402.6	44.8	31.33	15.22	8
ZNP	2.17	0.10	14.1	110.3	27.8	6.91	1.33	10
ZJT	4.45	0.17	96.8	143.3	11.7	16.64	5.56	4
QKP	4.18	0.15	59.5	129.3	112.2	6.92	1.29	5
XHL	3.75	0.24	33.5	113.8	47.2	3.06	0.43	3
DDH	4.90	0.13	185.7	45.2	408.5	8.77	1.97	5
XDH	1.91	0.03	31.7	20.9	366.8	7.35	1.38	3
KLP	5.96	0.41	88.0	311.0	23.4	15.37	5.23	5
NYR	1.04	0.55	29.4	5.6	124.3	2.05	0.75	4
HSH	1.82	0.075	39.7	25.2	132.4	9.49	4.13	4
CBG	1.09	0.079	35.2	23.8	264.3	5.96	2.28	1
All	3.25	0.44	48.4	104.2	87.0	10.12	3.26	211
NOF	4.12	0.73	54.7	149.3		16.11	5.73	78
OF	2.02	0.13	42.1	38.9		5.47	1.67	133

HESSD
10, 6559–6597, 2013

Spatiotemporal characterization of dissolved carbon for inland waters

K. S. Song et al.

Table 3. Seasonal variability of water quality parameters and CDOM absorption features for the Shitoukoumen Reservoir (STR) and for Chagan Lake (CGL); all water quality parameters have the same units as shown in Table 2.

	Date	TN	TP	Chl *a*	TSM	Salinity	pH	$a_{CDOM}(355)$	$a_{CDOM}(440)$	*N*
STR 1	20 May 09	2.80	0.14	12.06	60.15	–	7.86	4.34	1.71	17
STR 1	13 Jun 08	1.25	0.06	24.25	21.77	0.13	8.53	6.15	2.84	18
STR 3	27 Jul 09	1.03	0.12	6.98	14.51	0.13	8.43	5.32	2.06	22
STR 4	29 Aug 09	0.99	0.07	7.32	38.51	0.12	8.31	5.82	2.46	25
STR 5	23 Sep 08	1.09	0.08	35.23	23.79	0.13	8.54	5.96	2.28	20
STR 6	7 Oct 10	1.17	0.09	18.7	18.7	0.13	8.71	4.57	1.83	7
Subtotal	–	1.35	0.09	17.4	35.80	0.13	8.42	5.56	2.28	109
CGL 1	3 May 11	2.06	0.073	6.34	57.55	0.29	8.63	26.13	8.84	18
CGL 2	14 Jun 08	2.01	0.13	11.6	43.2	0.37	9.07	13.5	6.87	8
CGL 2	15 Jul 09	3.28	0.24	14.31	190.12	0.76	9.61	34.02	19.74	20
CGL 3	29 Aug 09	2.21	0.182	9.82	233.08	0.48	9.10	10.26	4.64	19
CGL 4	13 Sep 10	1.82	0.075	39.67	25.19	0.66	9.30	9.49	4.13	25
CGL 5	12 Oct 09	1.82	0.054	4.58	66.81	0.67	9.27	6.76	2.73	17
Subtotal	–	2.24	0.125	14.95	114.52	0.57	9.20	17.50	7.93	107

HESSD
10, 6559–6597, 2013

Table 4. Multi-regression analysis of DOC (DIC) against accumulated climatic variables in one month before field surveys were conducted (*P*, precipitation; ET_0, potential evaporation; *S*, sunshine duration hours) over 26 water bodies across the Songnen Plain.

	Intercept	Slope			Statistics			
		P	ET_0	*S*	*R* square	Adj. *R* square	*F* value	*p* value
DOC	−135.38	0.18	0.93	0.11	0.33	0.27	4.13	0.024
DIC	−1823.77	2.89	0.71	5.99	0.34	0.26	3.78	0.032

HESSD
10, 6559–6597, 2013

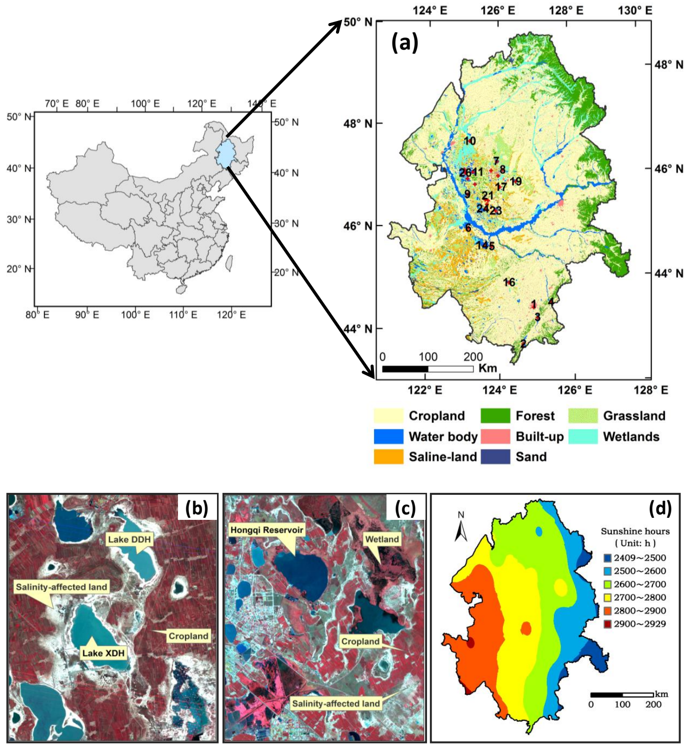

Fig. 1. (a) Map of sampling locations with various land use/land cover types. The water bodies are: 1 Nanhulake, 2 Erlonghu, 3 Xinlicheng, 4 Shitoukoumen Reservoir, 5 Xinmiao Lake, 6 Yueliang Lake, 7 Daqing Reservoir, 8 Hongqi Reservoir, 9 Lamasi, 10 Dongsheng Reservoir, 11 Longhupao, 12 Yuebingpao, 13 Yueliangpao, 14 Chagan Lake, 15 Talahong Reservior, 16 Boluo Lake, 17 Zhongneipao, 18 Zhaojiatun, 19 Qingkenpao, 20 Xinhua Lake, 21 Dongdahai, 22 Xidahai, 23 Kulipao, 24 Nanyin Reservoir, 25 Huoshaohei, 26 Cuibaguzi. **(b)** Lake Dongdahai, Xidahai, **(c)** Hongqi Reservoir with their ambient environments, and **(d)** Sunshine duration characteristics for the Songnen Plain.

HESSD
10, 6559–6597, 2013

Spatiotemporal characterization of dissolved carbon for inland waters

K. S. Song et al.

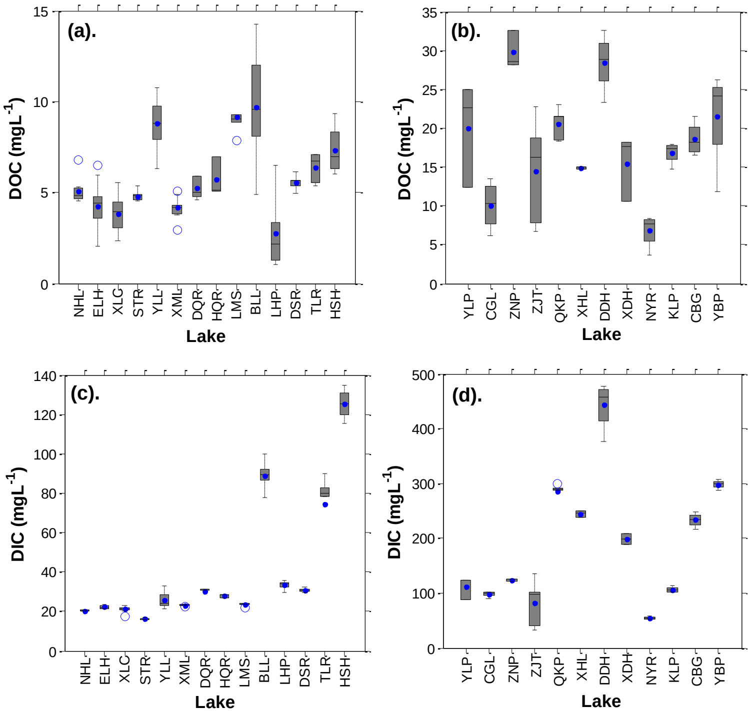

Fig. 2. Spatial variation of dissolved carbon (dissolved organic carbon: DOC; dissolved inorganic carbon: DIC) concentrations in water bodies across the Songnen Plain; **(a)** and **(c)** are DOC and DIC in fresh waters, and **(b)** and **(d)** are DOC and DIC in brackish waters. The black line and the blue filled circles represent the median and mean respectively. The horizontal edges of the boxes denote the 25th and 75th percentiles; the whiskers denote the 10th and 90th percentiles and the blue circles represent outliers. The abbreviated names of water bodies are listed in Table 1.

HESSD
10, 6559–6597, 2013

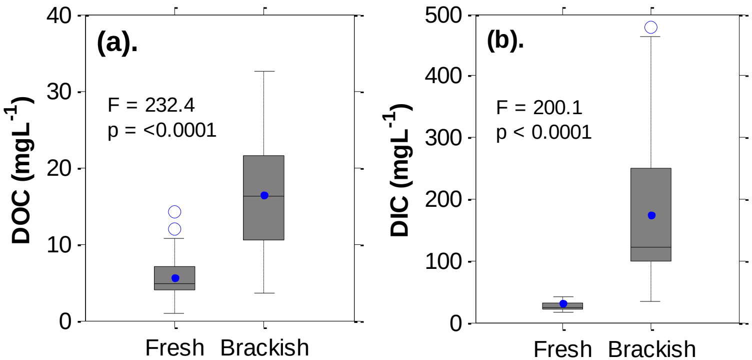

Fig. 3. Box plots of DOC **(a)** and DIC **(b)** for fresh and brackish waters in the Songnen Plain. The black line and the blue filled circles represent the median and mean respectively. The horizontal edges of the boxes denote the 25th and 75th percentiles; the whiskers denote the 10th and 90th percentiles and the blue circles represent outliers.

HESSD
10, 6559–6597, 2013

Spatiotemporal characterization of dissolved carbon for inland waters

K. S. Song et al.

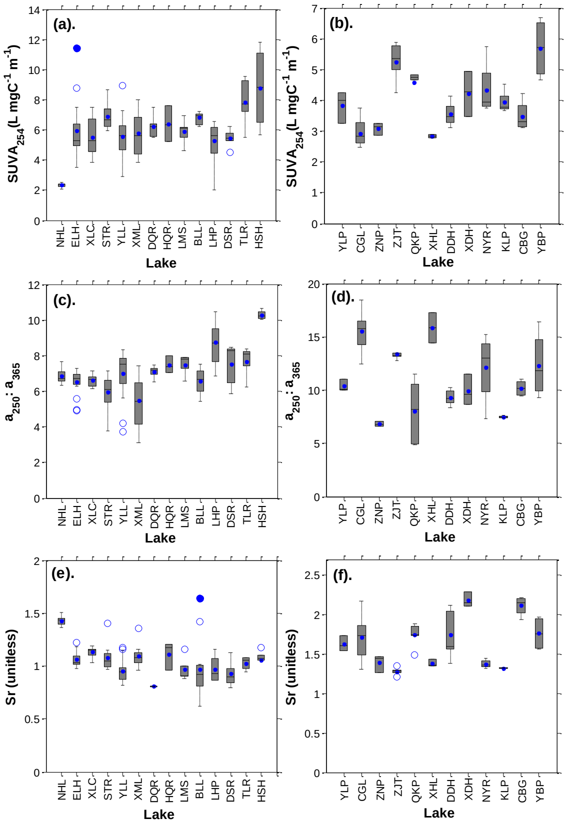

Fig. 4. Box plots for specific UV absorption coefficients ($SUVA_{254}$), CDOM absorption ratio ($a_{250}:a_{365}$) and spectral absorption ratios (Sr) in fresh waters **(a, c, e)** and brackish waters **(b, d, f)** across the Songnen Plain. The names of the water bodies are listed in Table 1. The black line and the blue filled circles represent the median and mean respectively. The horizontal edges of the boxes denote the 25th and 75th percentiles; the whiskers denote the 10th and 90th percentiles and the blue circles represent outliers.

HESSD
10, 6559–6597, 2013

Spatiotemporal characterization of dissolved carbon for inland waters

K. S. Song et al.

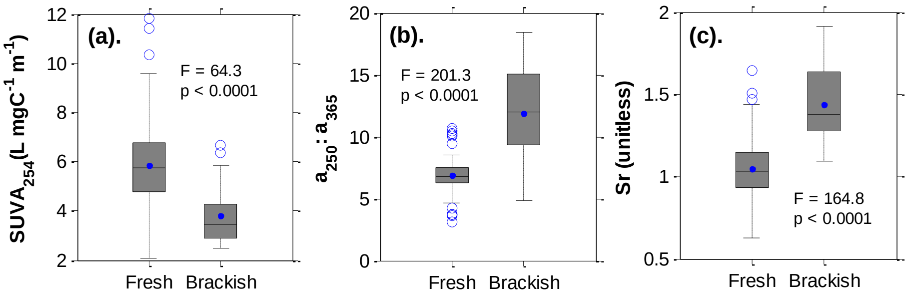

Fig. 5. Box plots of **(a)** $SUVA_{254}$, **(b)** CDOM ratio ($a_{250} : a_{365}$) and **(c)** spectral slope ratio (Sr: $S_{275-295} : S_{350-400}$ nm) between fresh and brackish waters in the Songnen Plain. The black line and the blue filled circles represent the median and mean respectively. The horizontal edges of the boxes denote the 25th and 75th percentiles; the whiskers denote the 10th and 90th percentiles and the blue circles represent outliers.

HESSD
10, 6559–6597, 2013

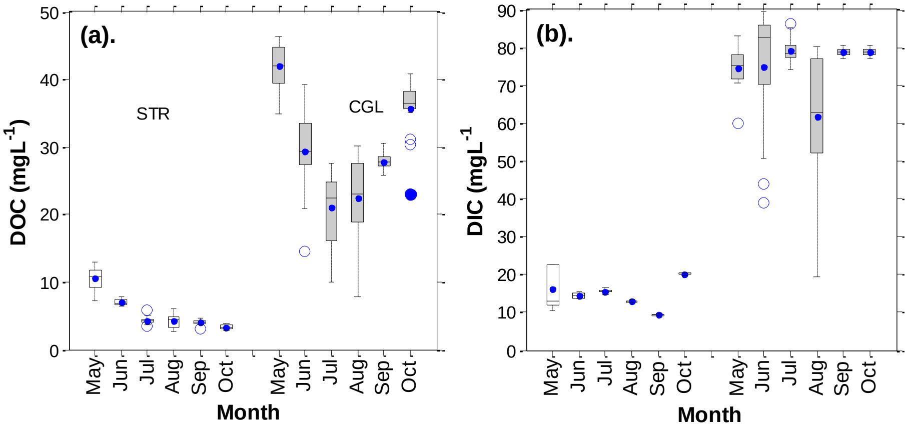

Fig. 6. Box plots of dissolved carbon in fresh and brackish waters during Ice-free season: **(a)** DOC and **(b)** DIC for Shitoukoumen Reservoir (STR) and Chagan Lake (CGL). The black line and the blue filled circles represent the median and mean respectively. The horizontal edges of the boxes denote the 25th and 75th percentiles; the whiskers denote the 10th and 90th percentiles and the blue circles represent outliers.

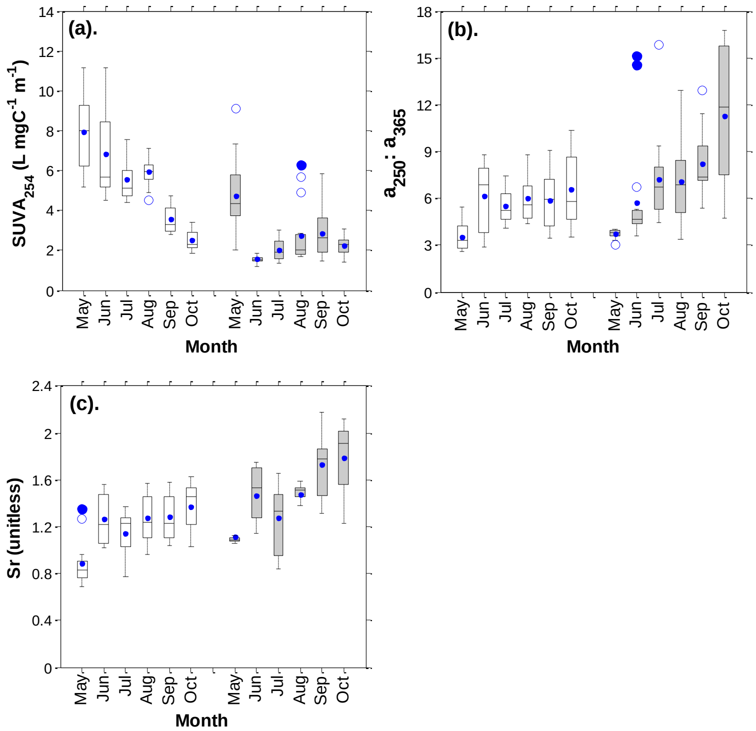

Fig. 7. Box plots of **(a)** $SUVA_{254}$, **(b)** $a_{250} : a_{365}$ and **(c)** *Sr* for Shitoukoumen Reservoir (empty box) and Chagan Lake (filled box) in various seasons. The black line and the blue filled circles represent the median and mean respectively. The horizontal edges of the boxes denote the 25th and 75th percentiles; the whiskers denote the 10th and 90th percentiles and the blue circles represent outliers.

HESSD
10, 6559–6597, 2013

Spatiotemporal characterization of dissolved carbon for inland waters

K. S. Song et al.

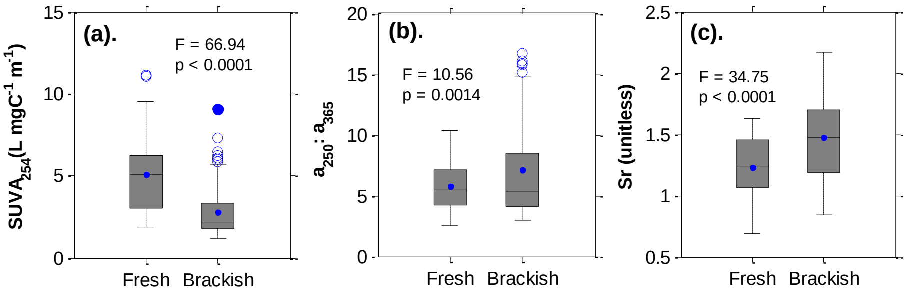

Fig. 8. Box plots of colored dissolved organic matter (CDOM) absorption between Shtioukoumen Reservoir (fresh) and Chagan Lake (brackish) in different seasons, **(a)** $SUVA_{254}$, **(b)** CDOM ratio ($a_{250} : a_{365}$) and **(c)** spectral slope ratio (Sr: $S_{275-295} : S_{350-400}$ nm). The black line and the blue filled circles represent the median and mean respectively. The horizontal edges of the boxes denote the 25th and 75th percentiles; the whiskers denote the 10th and 90th percentiles and the blue circles represent outliers.

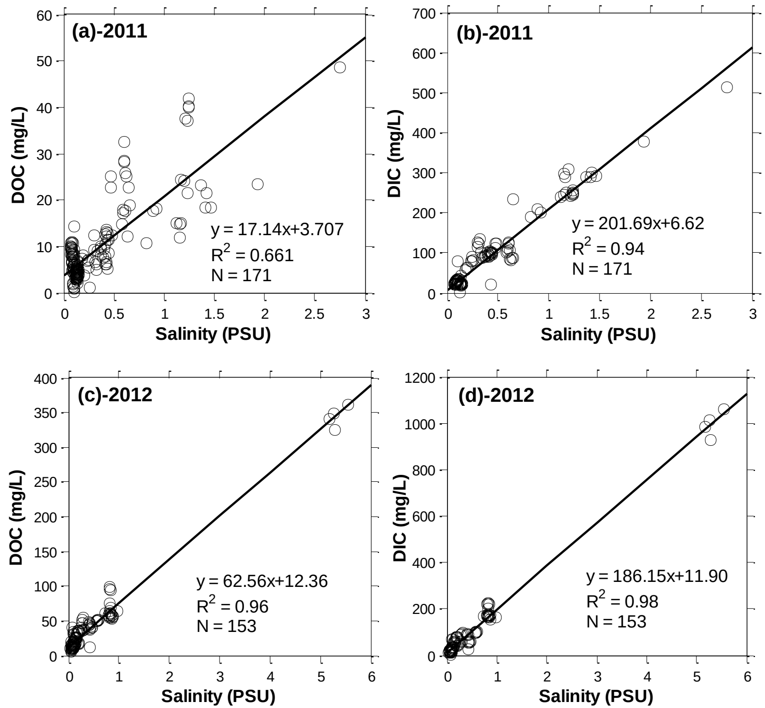

Fig. 9. Correlation between dissolved carbon and salinity (PSU) in water bodies across the Songnen Plain. **(a)** DOC vs. salinity and **(b)** DIC vs. salinity for 2011 data set; **(c)** DOC vs. salinity and **(d)** DIC vs. salinity for 2012 data set.

HESSD

10, 6559–6597, 2013

Spatiotemporal characterization of dissolved carbon for inland waters

K. S. Song et al.

Title Page
Abstract | Introduction
Conclusions | References
Tables | Figures
◄| |►
◄ ►
Back | Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion