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Mechanisms controlling dissolved CO_2 over-saturation in the Three Gorges Reservoir area

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Abstract: The loss of CO_2 to the atmosphere from inland waters is an important part of the global carbon cycle. The Three Gorges Dam is the largest hydraulic project in the world and has consequently been widely studied. Here, we made spatially and temporally comprehensive measurements of partial pressure of CO_2 (pCO_2) variability along the Three Gorges Dam system. The pCO_2 ranged from 619 to 2383 μatm for the collected samples, and were supersaturated relative to atmospheric CO_2. At the station near the upstream part of the reservoir, the pCO_2 at high-flow was much lower than that at low-flow. In contrast, pCO_2 at high-flow is much higher than that in the low-flow for the waters in front of the dam and after the dam. Rates of organic matter mineralization increased at high-flow, which produced increased pCO_2 in the surface water of the reservoir area. Mineralization of organic carbon should be responsible for the $\delta^{13}C$-depleted of riverine DIC. Organic carbon mineralization is sensitive to temperature variability, and temperature is expected to be an important driver of the dissolved CO_2 over-saturation. The construction of Three Gorges Reservoir increased the water transit time and accelerated the organic carbon mineralization in Three Gorges Reservoir. The results suggest that carbon cycling changes markedly in large rivers that have been impounded.

Keywords: pCO_2, Three Gorges Reservoir, organic carbon mineralization, $\delta^{13}C_{DIC}$, temperature sensitivity

Introduction: Inland waters link terrestrial and oceanic ecosystems by transporting materials from land to ocean (Barth et al., 2003; Wang et al., 2014b) and also exchange material with the atmosphere (Kosten et al., 2010; Raymond et al., 2013). Although the fluvial carbon export by inland water only occupies a small portion (10^{15} g C $year^{-1}$) of the global carbon cycle (Aucour et al., 1999; Meybeck, 1982), it plays an important role in regional carbon cycling (Wang et al., 2014b). However, in the last few decades, the natural fluvial processes in many rivers have been disturbed by anthropogenic activities (Guo et al., 2015; Humborg et al., 1997; Raymond et al., 2008; Regnier, 2013), and the consequences of dam construction have been intensively studied (Bao et al., 2014; Barros et al., 2011; Humborg et al., 1997; Wang et al., 2014a; Wang et al., 2013; Wang et al., 2011). Impoundment converts a river into an "artificial lake", and consequently modifies the ecological function and biogeochemical processes of the inland water. River regulation by dam construction has become an important environmental problem affecting greenhouse gas release from rivers although hydropower is regarded as a "green energy" (Chen et al., 2011; Humborg et al., 1997; Wang et al., 2011). Enhanced dam construction in rivers has greatly changed the transport of sediment, dissolved silica and terrestrial organic carbon (Bao et al., 2014;Humborg et al., 1997; Yang et al., 2015; Yang et al., 2007a; Yang et al., 2007b; Yu et al., 2011). The construction of dams would moderate the organic matter fluxes and compositions downstream, and the trapping of sediment within a reservoir would result in intensive respiration, thus increasing the proportion of aquatic carbon, as well as CO_2 emission from inland waters (Bao et al., 2014).

The Three Gorges Dam is the largest hydropower dam in the world, and the ecological environment and biogeochemical processes in the Three Gorges Reservoir have been widely studied (e.g. Bao et al., 2014; Yang et al., 2007b; Zhang et al., 2014). Previous studies have estimated the changes in hydrology and sediment dynamics in the Three Gorges Reservoir (Dai and Liu, 2013; Deng et al., 2016; Li et al., 2016; Xu and Milliman, 2009; Yang et al., 2015), biogeochemistry (Bao et al., 2014; Mao et al., 2017) and greenhouse gases emissions (Chen et al., 2011; Zhao et al., 2013). However, few studies have focused on the sources of the dissolved CO_2 and the relative biogeochemical processes in inland waters. Artificial reservoirs are known to be potential CO_2 contributors to the atmosphere (Raymond et al., 2013; Wang et al., 2015). Dissolved CO_2 over-saturation with respect to the atmosphere is the main driver of CO_2 emissions. Multiple control mechanisms have been proposed for the CO_2 over-saturation in inland waters. Maberly et al. (2013) found that catchment productivity controls CO_2 emissions for lakes. Marcé et al. (2015) showed that carbonate weathering is a driver of CO_2 over-saturation in lakes. Inorganic carbon loading was regarded as a primary driver of dissolved CO_2 concentrations in lakes and reservoirs of the contiguous United States (McDonald et al., 2013). Ward et al. (2013) found that degradation of terrestrial macromolecules contributes significantly to CO_2 out-gassing from inland waters.

In this study we investigated the temporal and spatial patterns of dissolved inorganic carbon (DIC), dissolved organic carbon (DOC), particulate organic carbon (POC), the partial pressure of CO_2 (pCO_2) and stable carbon isotope of DIC ($\delta^{13}C_{DIC}$)

in surface water of the Three Gorges Reservoir area. The objectives of the study are to: (1) investigate the carbon dynamics in the Three Gorges Reservoir, (2) trace the main sources of the dissolved CO_2 in the Three Gorges Reservoir, (3) analyze the controlling mechanisms of the dissolved CO_2 over-saturation.

Study site

As the largest hydropower project in the world, the Three Gorges Reservoir (TGR, Fig. 1) is located between the upper and middle reaches of the Changjiang River, upstream of Yichang city in Hubei province (Deng et al., 2016; Zhao et al., 2013). Three Gorges Reservoir is a narrow V-shaped valley-type reservoir with steep slopes of the river channel. Mountainous areas occupy up to 96% of the Three Gorges Reservoir area, with 4.3% plain area only in the river valley (Zhao et al., 2013). The Three Gorges Reservoir experiences a humid subtropical monsoon, with an annual mean temperature of 18□ (Mao et al., 2017). The local annual rainfall is approximately 1250 mm and occurs mainly from May to September (Mao et al., 2017).

The Three Gorges Reservoir has been fully operational since the end of 2008 (Zhao et al., 2013). The water level ranges from 145 m at high-flow to control floods and 175 m at low-flow to retain water, with corresponding storage capacities of 17.2 and 39.3 km^3, respectively (Yang 2014). High-flow is defined as from May to October and low-flow as from November to April of the subsequent year, based on water regulation at the Three Gorges Reservoir, according to the water level.

Methods

Six sampling sites (QX, WZ, ZZ, TPX, HL and YC) were chosen in the Three Gorges Reservoir area (Fig. 1), of which four sampling sites (QX, TPX, HL and YC) were chosen for long-term observation. QX is located near the inflowing water of the reservoir, WZ, ZZ and TPX are located sequentially down-stream within the reservoir and HL and YC are located downstream of the water discharged from the Three Gorges Reservoir and Gezhou dams, respectively. We collected samples at QX, monthly, for two hydrological years, and added extra sampling occasions during high-flow. TPX, HL and YC were sampled, monthly, for a hydrological year, and additional samples were added during high-flow.

Water temperature (T), pH and Electric Conductivity (EC) were measured directly at the time of sampling for the surface water using a portable EC/pH meter (WTW, pH 3210/Cond 3210 Germany). Water samples were collected in sealed high density polyethylene (HDPE) bottles and the alkalinity was measured by Gran titration with 0.02 M HCl within 24 hours of sampling. The concentration of DOC was analyzed using an OI Analytical Aurora 1030 TOC analyzer. Total suspended solids (TSS) were trapped on a glass-fibre filter paper (0.7μm, Whatman, GF/F) and then freeze dried and weighed. Particulate organic carbon (POC) was measured with an elemental analyzer (PE2400 (Ⅱ), Perkin Elmer) after acidification. The $\delta^{13}C_{DIC}$ was determined by the method of Li et al., (2010), 20 ml aliquots of water were purified on a vacuum line with 2 ml 85% phosphoric acid and magnetic stir bars, with

a precision of 0.2 ‰. Daily water discharge and water level data were obtained online from the Ministry of Water Resources (http://www.hydroinfo.gov.cn/). The pCO_2 was calculated based on mass balance relationships and the relative equilibrium constants.

Results

Hydrological characteristics

Although the Changjiang River carries a tremendous volume of water, the Three Gorges Dam can moderate the downstream delivery of water. The water level ranged from 145 m to 175 m above the sea level in the study period (Fig. 1). The Changjiang river water is retained in the Three Gorges Reservoir in the low-flow season, and the water level is kept at a relatively high level to meet water navigation and hydropower requirements (Fig. 1). The water level is decreased to a low level from April to June, to provide capacity for flood control (Fig. 1). From September to October, the water level is increased to impound water, and a high level is maintained during the dry season (Fig. 1). At QX, in the upper reaches of the reservoir, discharge varied from 4293 to 36484 m^3s^{-1}, with an average of 10242 m^3s^{-1} from February 2015 to February 2016. Because of the water regulation, discharge is less variable at HL and YC: from 5050 to 31800 $m^{-3}s^{-1}$ and from 5620 to 32600 $m^{-3}s^{-1}$, respectively. However, the average discharge was not significantly different at the three hydrological stations, indicating that the contribution of other inflowing rivers is minor.

Variations of carbon species and $\delta^{13}C_{DIC}$ in the TGR

The range of temporal variations of water environment variables was much larger than that of spatial variation. Temperature varied seasonally from 11.2 to 28.9□ and there was little variation between water temperature in the surface water of the reservoir (TPX) and the discharged water at HL. This is markedly different to other reservoirs (Wang et al., 2014b), which may be caused by the weak stratification in the Three Gorges Reservoir (Wu et al., 2012). The pH value varied from 7.75 to 8.31 for all the samples, with little spatial variation. Conductivity varied from 295 to 410 μScm^{-1}, with both the maximum and minimum values observed in QX. The more stable status of the other sites could be ascribed to the regulating effect of the Three Gorges Reservoir. DOC ranged from 0.86 to 2.05 mgL^{-1}, again with lower spatial variation than temporal variation. Alkalinity ranged from 1.97 $mequivL^{-1}$ to 2.60 $mequivL^{-1}$, and the alkalinity at QX was higher than at other stations. The pCO_2 ranged from 619 to 2383 μatm (Fig. 2a), and so all the samples are supersaturated relative to atmospheric CO_2 and hence sources to the atmosphere. The pCO_2 values of samples in WZ and ZZ are between that of QX and TPX in January, 2016. The pCO_2 values decreased from QX to YC in the low-flow season, and increased in the high-flow season (Fig. 2a). The pCO_2 values were higher in the low-flow season (1150 ± 343μatm) than in the high-flow season (987 ± 309 μatm) at QX, but the pCO_2 values were lower in the low-flow season at the other sites (Fig. 2a). The pCO_2 in the reservoir area is always lower than in the inflowing water and the out-flowing water in reservoirs of Southwest China. However, Similar pCO_2 values between reservoir area and the out-flowing water were occurred for TGR (Fig. 2a). The $\delta^{13}C_{DIC}$ varied

from -13.2‰ to -6.6‰ for all the samples, and the $\delta^{13}C_{DIC}$ of QX was much heavier than at other stations, especially at high-flow (Fig. 2b).The $\delta^{13}C_{DIC}$ values were lower in the high-flow season at all sites.

Discussion:

Response of pCO_2 and $\delta^{13}C_{DIC}$ to hydrological change

Emissions of CO_2 from the water to the atmosphere have been explored in relation to CO_2 sources and processes (Whitfield et al., 2010) including soil CO_2 discharge, *in situ* degradation of organic carbon, CO_2 degassing rates, carbonate weathering, inorganic carbon loading and photosynthesis (Johnson et al., 2008; Larsen et al., 2011; Li et al., 2010; Maberly et al., 2013; Marcé et al., 2015; McDonald et al., 2013). There is a negative correlation between pCO_2 and discharge near the upper reaches of the reservoir at QX (Fig. 3a), indicating a dilution effect by overland flow at high-flow. pCO_2 was lower in high-flow than in low-flow, but pCO_2 was variable in both seasons (Fig. 3a) indicating that hydrological variation is not the main controller of pCO_2 at QX, and other effects are important. The negative correlation between pCO_2 and discharge shows that pCO_2 exhibits strong biogeochemical stationarity (relatively stable behavior in response to changing discharge). Soil CO_2 discharge or degradation of organic matters may be responsible for this biogeochemical stationarity with high-discharge, which is similar to studies in Wujiang (Zhong et al., 2017).

There was a large dynamic range of $\delta^{13}C_{DIC}$ values at QX, with a minimum at the

192 high-flow and a maximum at the low-flow (Fig. 3b). The $\delta^{13}C_{DIC}$ was negatively
193 correlated to the discharge for QX (Fig. 3b). Negative $\delta^{13}C_{DIC}$ values were related to
194 higher discharge, which should not be ascribed to simple dilution. High
195 concentrations of CO_2 derived from terrestrially fixed carbon broken down in the soil
196 can enter the water directly (Maberly et al., 2013). Large amounts of soil CO_2 were
197 discharged into the river during high discharge, producing more negative $\delta^{13}C_{DIC}$
198 values in the water (Li et al., 2010; Zhong et al., 2017). Mineralization of
199 macromolecules in the channel can also produce lighter $\delta^{13}C_{DIC}$ values in the water
200 (Ward et al., 2013). Soil CO_2 recharge is likely to be the main driver of CO_2 dynamics
201 responding to hydrological variation in QX (Zhong et al., 2017).

202 A negative relation between pCO_2 and discharge occurred at QX (Fig. 3a),
203 however, there were positive relationships between pCO_2 and discharge at HL and YC
204 (Fig. 4a), both of which are located downstream of the TGD. The positive relationship
205 contrasts to the relationship at QX (Fig. 3a), with no dilution occurring in the
206 high-flow season at HL and YC (Fig. 4a). Higher values of pCO_2 were recorded with
207 high discharge, which is contrary to QX, ascribing to multiple biogeochemical
208 processes in the reservoir. Biogeochemical processes occurring in the Three Gorges
209 Reservoir may be responsible for the pCO_2over-saturation at TPX, HL and YC (Abil
210 et al., 2013; Algesten et al., 2005; Brothers et al; 2012; McDonald et al., 2013;
211 Weyhenmey et al.; 2015). Thus, $\delta^{13}C_{DIC}$ values were significantly and negatively
212 correlated to increasing discharge (Fig. 4b).

213

214 Relationships between pCO_2 and organic carbon concentration

215 Transformation between inorganic and organic forms of carbon will alter the
216 pCO_2 in inland waters. When terrestrial or autochthonous organic carbon is
217 mineralized, CO_2 is produced in the reservoir (Kosten et al., 2010), while
218 phytoplankton productivity will remove CO_2 from the water (Wang et al., 2015).
219 Although there was no relation between pCO_2 and discharge at QX, The pCO_2 values
220 at HL and YC were positively related to the DOC concentration (Fig. 5a and 5b),
221 which is similar to the results of Larsen et al., (2011) and Sobek et al., (2005). CO_2
222 over-saturation at HL and YC may be derived from the degradation of DOC in
223 high-flow. DOC is largely in the form of allochthonous C, and terrigenous C is an
224 important form of total C in the inland waters (Hope et al., 1996; Striegl et al., 2001;
225 Whitfield et al., 2010). In spite of the low contents, allochthonous DOC
226 mineralization may be an important driver of CO_2 over-saturation. Although there is
227 no marked spatial variation of DOC in the Three Gorges Reservoir areas, allothogenic
228 DOC inputs should counteract the effect of DOC degradation. Intense photosynthesis
229 and submerged respiration would induce both high DOC and pCO_2 concentrations in
230 the high-flow season.

231 Particulate organic carbon (POC) can be present at high concentration within the
232 Three Gorges Reservoir system and is strongly related to the concentration of total
233 suspended matter (TSM). TSM in surface waters of the Changjiang main stream
234 ranged from 0.9 to 123.6 mgL^{-1}. The relationship between POC% (POC/TSM×100%)
235 and Total Suspended Matters (TSM) followed that found previously (Zhang et al.,

236 2014) showing the power-law function: $POC\%=16.59\times TSM^{(-0.57)}$ for samples
237 collected both upstream and downstream. The same pattern in both upstream and
238 downstream sites indicated that the Three Gorges Reservoir did not have a major
239 effect on the relationship between POC% and TSM (Fig. 6a).

240 There was a significant positive correlation between pCO_2 concentration and
241 POC were found at HL and YC (Fig. 6b), indicating that POC mineralization may be
242 a source of pCO_2 over-saturation in the Three Gorges Reservoir. Large amounts of
243 POC were present at high discharge in the high-flow season. At the same time, the
244 POC mineralization increased in the high-flow season with high POC concentrations
245 contributing to the pCO_2 over-saturation. Dai and Liu (2013); Xu and Milliman
246 (2009); Yang et al. (2014); Yang et al. (2007b) have found that the Three Gorges
247 Reservoir traps the sediment noticeably. The contribution from sediment respiration to
248 summer CO_2 emission is significant for boreal and subarctic lakes (Algesten et al.,
249 2005). So it is difficult to qualify the contribution of POC decomposition for water
250 pCO_2 over-saturation. However, these results are consistent with other studies that
251 show mineralization and degradation of organic carbon is a main diver of pCO_2
252 over-saturation (Algesten et al., 2005; Hope et al., 1996; Sobek et al., 2005; Ward et
253 al., 2013; Weyhenmeyer et al., 2012; Whitfield et al., 2010).

254 In recent years, isotope proxies application has become invaluable in studying
255 the riverine carbon cycle (Tamooh et al., 2013). $\delta^{13}C_{DIC}$ signatures have been used to
256 trace DIC sources, transport and transformation in inland waters based on the distinct
257 isotopic values of various carbon sources (Barth et al., 2003; Goodwin et al., 2016; Li

et al., 2010; Tamooh et al., 2013; Zhong et al., 2017). Riverine $\delta^{13}C_{DIC}$ dynamics are primarily controlled by both chemical weathering in the catchment and biogeochemical processes in inland waters. In general, carbonate weathering and biological CO_2 dissolution are two primary DIC sources, and photosynthesis, calcite precipitation and CO_2 degassing are primary mechanisms of DIC transformation and loss. At QX, soil CO_2 discharge and organic carbon decomposition should be responsible for the DIC temporal dynamics for the soil CO_2 contribution from various tributaries (Zhong et al., 2017). Soil CO_2 discharge was related to the reactive contact surface between water and soil. The soil CO_2 discharge would play a minor role in DIC dynamics in the reservoir area, just because of the limited reactive surface of the soil. Both pCO_2 and $\delta^{13}C_{DIC}$ are negatively correlated with increasing discharge (Fig. 2a and 2b). Although the soil CO_2 discharged into the river, the dilution effect on pCO_2 can conceal the soil CO_2 discharge at QX.

Significant negative relationships between $\delta^{13}C_{DIC}$ and pCO_2 were presented in HL and YC (Fig. 6). Relatively higher pCO_2 concentrations with lighter $\delta^{13}C_{DIC}$ values were occurred in high-flow. Although the stratification is not significant in the reservoir area, the average residence time of water is from 6 to 30 days (Zhao et al., 2013). Thus, there is enough time for degradation of organic carbon. The over-saturation of pCO_2 in the Three Gorges Reservoir would result in out-gassing of dissolved CO_2 to the atmosphere. However, there are minor spatial variations for the water pCO_2. Inorganic carbon loading and organic carbon decomposition may be the primary driver of pCO_2 in the Three Gorges Reservoir. Inorganic carbon loading

would shift to $\delta^{13}C$-enriched DIC values, but the $\delta^{13}C_{DIC}$ values became more negative at TPX, HL and YC than that at QX. Therefore, inorganic carbon loading should not be regard as the primary driver of pCO_2 in the Three Gorges Reservoir. In general, the upper Changjiang catchment has C3 plant coverage, suggesting that the organic carbon will be depleted in ^{13}C in terms of water DIC for Three Gorges Reservoir. The water impoundment of the Three Gorges Reservoir would increase the riverine water transit time. Although the Three Gorges Reservoir releases flood water for the flood control in the high-flow season, the organic carbon increases with increased discharge, and mineralization and degradation of organic carbon likely contributes to elevated dissolved CO_2 (Whitfield et al., 2010). The biological CO_2 dissolution would shift the $\delta^{13}C_{DIC}$ to negative values. The relations of $\delta^{13}C_{DIC}$ versus pCO_2 are consistent with our hypothesis that organic carbon decomposition, depleted in ^{13}C, is responsible for the water pCO_2 over-saturation in the reservoir (Fig. 7). Therefore, the pCO_2 over-saturation in the Three Gorges Reservoir can be mainly elucidated as that soil CO_2 recharge for the inflowing water and mineralization and degradation of organic carbon in the reservoir area was the primary driver of CO_2 over-saturation.

Sensitivity of Temperature for pCO_2 in the TGR

Mineralization and degradation of organic carbon and primary productivity is sensitive to temperature (Acuna et al., 2008; Maberly et al., 2013; Sobek et al., 2005), which would regulate the water pCO_2. Negative relationship between pCO_2 and T was

found in QX, but the explained variance in pCO_2 by T was low (R^2=0.135, Fig. 8a). Due to the turbid and fast-flow water for the QX, especially in high-flow, the pCO_2 dynamics cannot be elucidated by primary production. As discussed above, dilution effects of pCO_2 and soil CO_2 recharge with inflowing of tributaries should control the pCO_2 dynamics. Therefore, temperature is not the primary driver of pCO_2 over-saturation at this site. The pCO_2 concentration increased with increasing T for TPX, HL and YC (Fig. 8b, 8c and 8d), supporting the hypothesis that lower ratios of primary production than organic carbon mineralization was occurred in the reservoir. High temperature stimulated high organic carbon mineralization rates, thus increasing the water pCO_2. Therefore, organic carbon degradation and mineralization should be responsible for the water pCO_2over-saturation, and high temperature is the primary driver of organic carbon mineralization.

pCO_2 in the waters is the main driver of CO_2 emission for inland waters. Mineralization of organic carbon is the main source for replenishing the dissolved CO_2 lost to the atmosphere or taken up by phytoplankton. The pCO_2 decreased along the main stream for the Three Gorges Reservoir area in the low-flow season (Fig. 2a), which should be ascribed to the aquatic CO_2 emission and low organic carbon mineralization rates with low T. The pCO_2 increased along the main stream for the Three Gorges Reservoir area in the high-flow season (Fig. 2a), indicating that the CO_2 produced by organic carbon mineralization is much higher than that lost as CO_2 emission to the atmosphere. Therefore, organic carbon mineralization is the primary driver of CO_2 over-saturation with respect to the atmosphere for Three Gorges

Reservoir.

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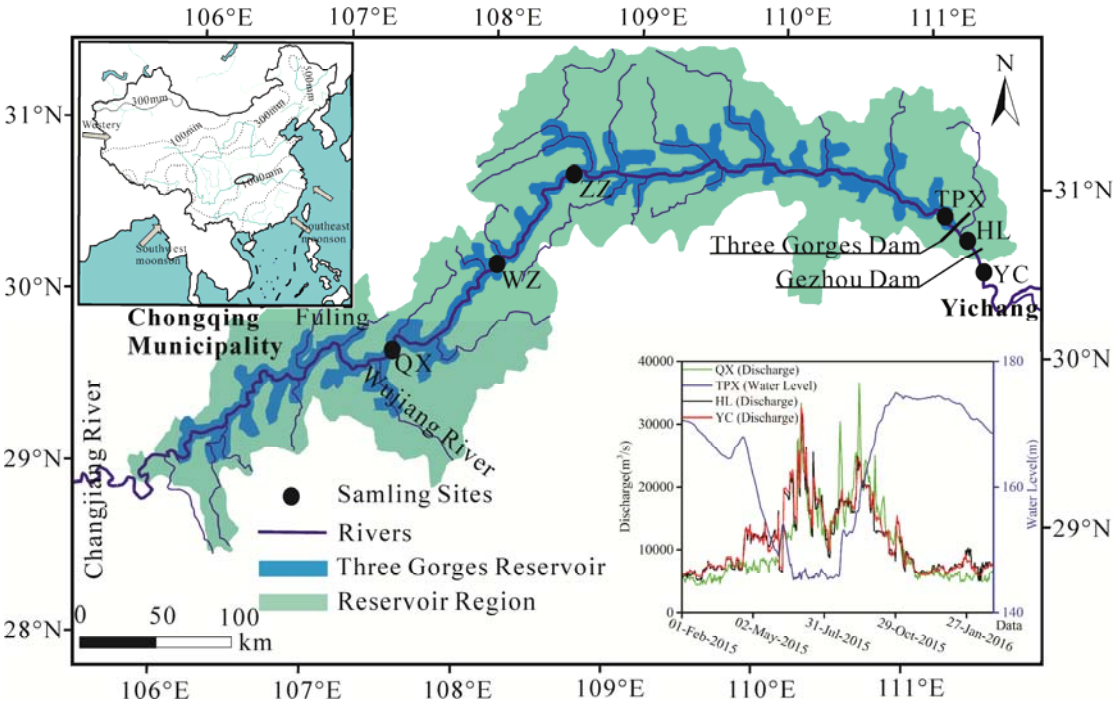

Figure. 1 The location of sampling sites in the Three Gorges Reservoir area. The sampling sites are at Qingxi (QX), Wanzhou (WZ), Zhongzhou (ZZ), Taipingxi (TPX), Huanglingmiao (HL) and Yichang (YC). The upper inset shows the location of the region within China and the lower inset shows discharge at QX, HL, YC, as well as water level at TPX for February, 2015 to February, 2016.

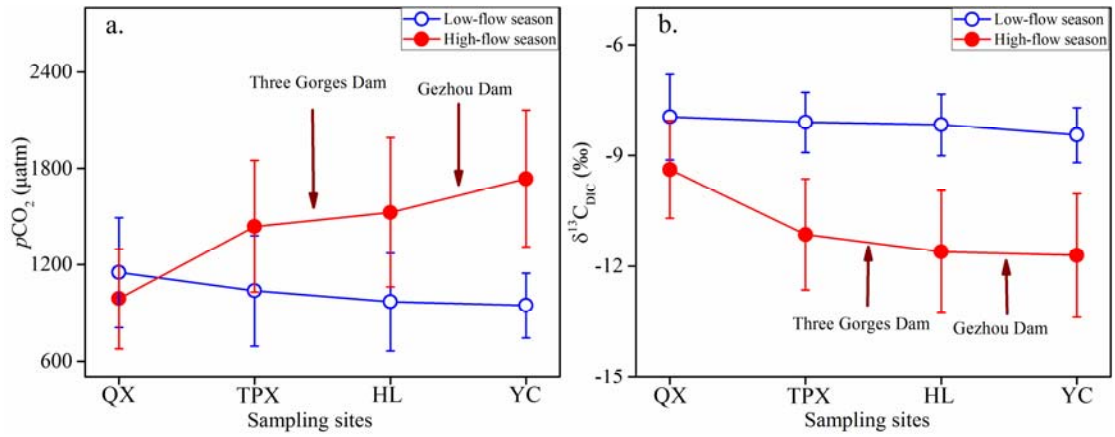

Figure. 2. Changes in pCO_2 and $\delta^{13}C$ at four sites along the Three Gorges Reservoir system at low and high flow. a. Variation in pCO_2; b. variation in $\delta^{13}C_{DIC}$. Average of all samples in each season is shown along with standard deviation.

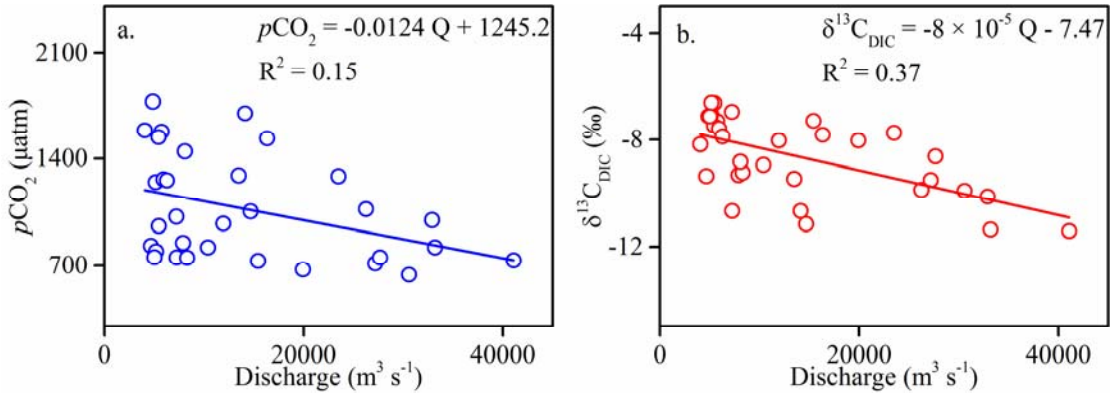

Figure 3. The relationship between pCO_2 or $\delta^{13}C_{DIC}$ and discharge at the upstream site on the Three Gorges reservoir Qingxi (QX). a. pCO_2 versus discharge; b. $\delta^{13}C_{DIC}$ versus discharge.

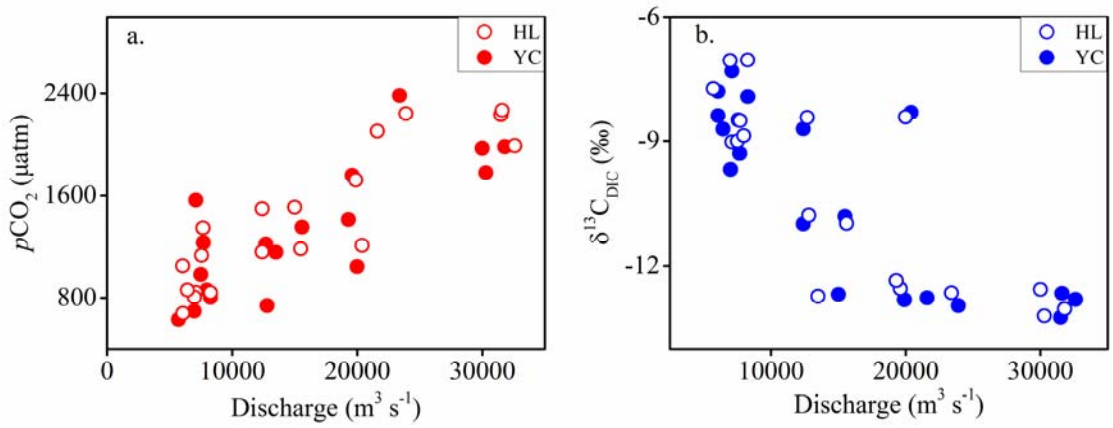

Figure. 4. The relationship between pCO_2 or $\delta^{13}C_{DIC}$ and discharge at Huanglingmiao (HL) and Yichang (YC). a. pCO_2 versus discharge; b. $\delta^{13}C_{DIC}$ versus discharge.

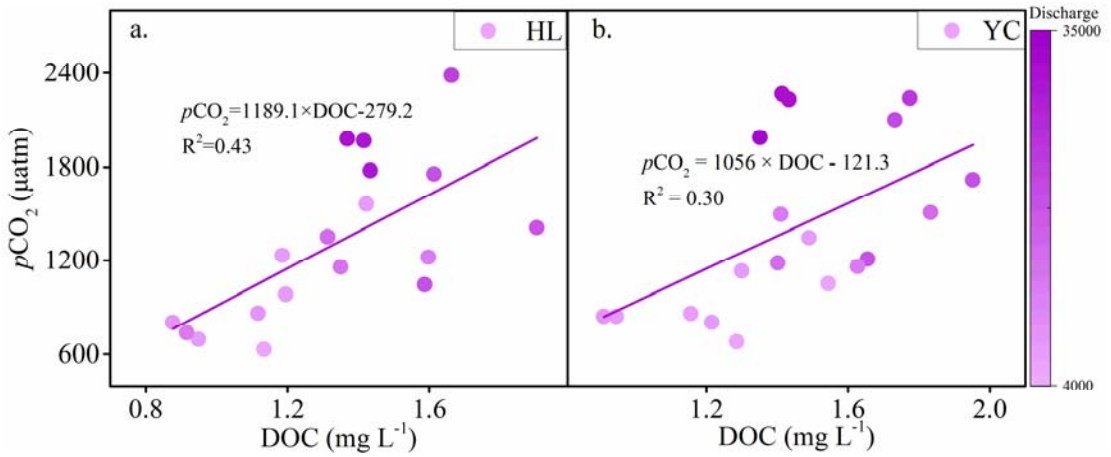

Figure. 5 Correlation between pCO_2 and concentration of DOC at Huanglingmiao (HL) (a) and Yichang (YC) (b) Discharge (m^3 s^{-1}) is indicated by the density of the symbol.

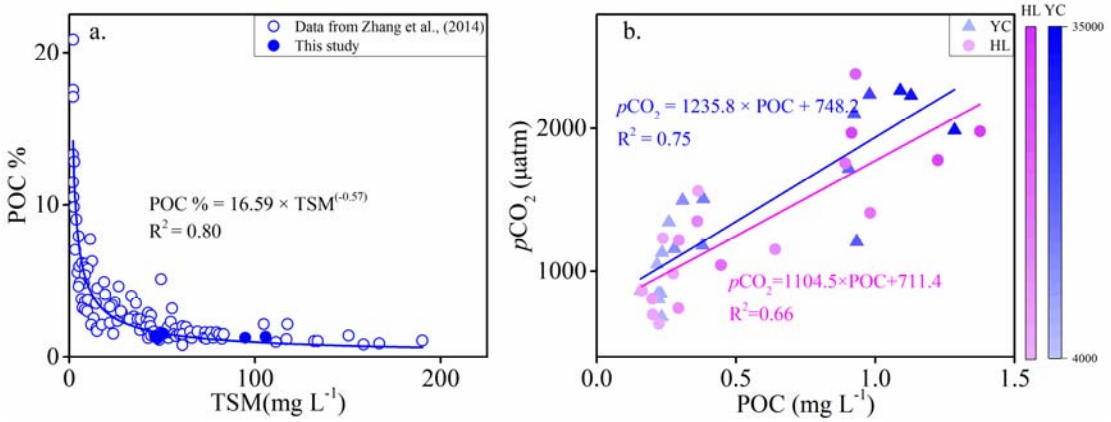

Figure. 6a. Relationships between POC and TSM or pCO_2 in the main stem of the Changjiang River. a. Relationship between POC% and TSM at this study in comparison to data from Zhang et al. (2014); b. Relationship between pCO_2 and POC at Huanglingmiao (HL) and Yichang (YC). Discharge (m^3 s^{-1}) is indicated by the density of the symbol.

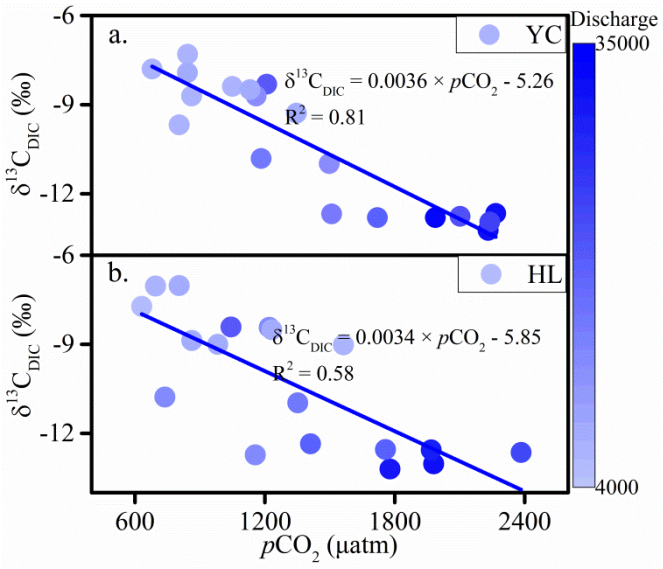

Figure. 7. Correlation between $\delta^{13}C_{DIC}$ and pCO_2 at a. Yichang (YC) and b. Huanglingmiao (HL). Discharge ($m^3\ s^{-1}$) is indicated by the density of the symbol.

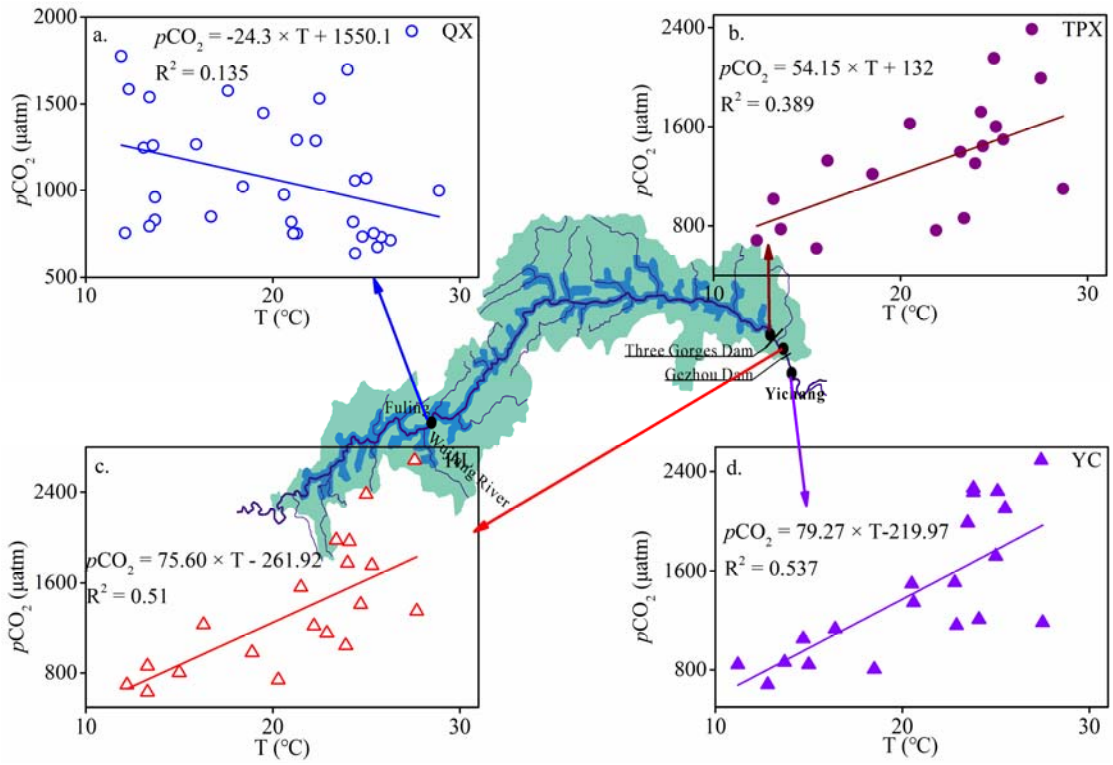

Figure. 8. Scatter plot of pCO_2 versus water temperature at: a. Qingxi (QX), b. Taipingxi (TPX), c. Huanglingmiao (HL) and d. Yichang (YC).