Dynamic biogeochemical controls on river pCO_2 with increasing river impoundment: an example of the Yangtze River

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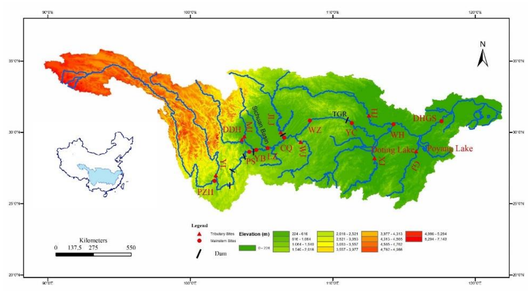
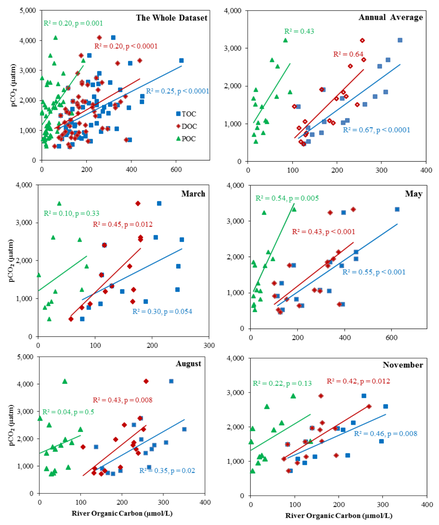
1. Summary

The research explores the pCO_2 biogeochemistry in one of the most important but significantly underrepresented river systems in the global aquatic pCO_2 landscape-the Yangtze River network. Heterotrophic respiration of terrestrially derived organic carbon in the water column is concluded as an essential but incomplete source of excessive dissolved CO_2 in the river. Significant benthic respiration and/or direct lateral transport of soil CO_2 (together makes up ~ 80%) must present to sustain pCO_2 under the current CO_2 emission rate. The research further sheds light on the effect of increasing channel impounding (typical for today's Asian rivers) on river pCO_2 by exploring the temporal and spatial distribution of chlorophyll a and the biogeochemical composition of river particulate organic carbon (POC). Although increased autotrophy (and pCO_2 decrease) is found in impounded sections (especially in nutrient rich rivers), the pCO_2 biogeochemistry is still dominated by terrestrial processes (e.g., transport of organic carbon and soil CO_2, and soil erosion, etc.) on the whole. The influence of sectional impounding on river CO_2 supersaturation is for the first time evaluated on the whole river scale and concluded to be temporal and regional (only 8% of the sites are significantly affected).

2. Study Area

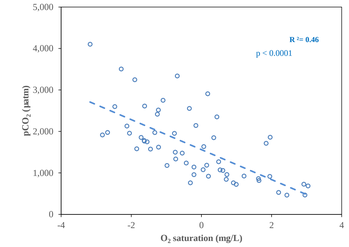


The research was conducted in the subtropical Yangtze River system. The nine sampling sites on the mainstem are Panzhihua (PZH), Pingshan (PS), Yibin (YB), Luzhou (LZ), Chongqing (CQ), Wanzhou (WZ), Yichang (YC), Wuhan (WH), and Datong Hydrological Gauging Station (DHGS). The eight major tributaries include Yalong Jiang (YL), Min Jiang (MJ), Dadu He (DDH, a tributary of MJ), Jialing Jiang (JLJ), and Han Jiang (HJ) on the north, the Wu Jiang (WJ) Xiang Jiang (XJ) and Gan Jiang (GJ) on the south. Among the sampling sites, PS and WZ on the mainstem and JLJ on the tributary are located in reservoirs. Fieldwork was conducted in 2014–2015.



Temporal variability in pCO_2 is minimal on most sites through the year (graph not shown). However, spatial (inter-river) pCO_2 varies significantly and correlates with riverine organic carbon species (DOC, POC and TOC). The seasonal independent correlations indicate that riverine CO_2 supersaturation is probably sustained by channel heterotrophic respiration of terrestrially-derived in the river. Alternatively, the correlations might also indicate co-occurrence of riverine pCO_2 and organic carbon species in the catchment.

3. Result and Discussion



Riverine pCO_2 is negatively correlated with dissolved O_2, clearly suggesting heterotrophic respiration of allochthonous organic carbon as a source of pCO_2 in the river. However, a primary calculation using field and literature data suggests heterotrophic respiration alone cannot sustain the observed pCO_2 and CO_2 flux (see right).

Estimated time & length for CO_2 exhaustion

- Dissolved CO_2 pool only: 1.1 days, or < 50 km downstream;
- TOC + dissolved CO_2: < 5 days, or 220 km downstream.
- Water column heterotrophic respiration represents only **8–22%** of the CO_2 flux; the rest (> 80%) comes from later soil CO_2 transport and/or benthic respiration.

Facts used for the above estimation of C flux

Channel depth: 5 m (conservative estimate)

Current velocity: 0.5 m/s (conservative estimate)

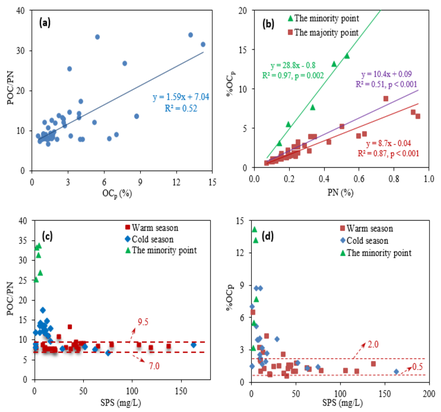
Average pCO_2: 1610 μatm (66 μmol l^{-1})

Average TOC: 225 μmol l^{-1}

Average CO_2 flux: 296 mmol m^{-2} day^{-1} (mean of 59 field measurements)

Heterotrophic respiration: 24–68 mmol m^{-2} day^{-1} (Zhai et al., 2007)

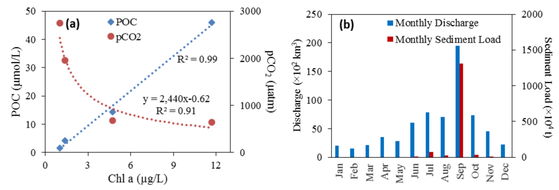
Suspended particulate sediment (SPS) at high concentrations show low POC:PN ratio (7.0–9.5) and $\%OC_p$ (0.5–2.0%), whereas at five (out of 59) low concentrations show high POC:PN (25–34) and $\%OC_p$ (3–14%) (b, c, d in the right figure). High OC suspended particulates indicate autochthonous POC, produced by floating vascular plants (e.g., **duckweed**) commonly found in nutrient-rich impounded areas (Qin et al., 2013).



The temporal and spatial distribution of POC compositional characteristics ($\%OC_p$ and POC/PN) indicate the dominant control of terrestrial processes (e.g., organic matter transport and soil erosion) on the river pCO_2 biogeochemistry, especially in warm seasons.

Table showing pCO_2, estimated autochthonous POC, and other biogeochemical characteristics of the affected sites. The group is associated with extremely low SPS, the highest POC/PN, high $\%OC_p$ and Chl a concentration, and low pCO_2 values, indicative of strengthened autotrophic activity at these points.

Site	Month	SPS (mg/L)	Chl a (μg/L)	POC/PN	$\%OC_p$	pCO_2 (μatm)	dCO_2 (μmol/L)	POC (μmol/L)	TOC (μmol/L)	Estimated auto. POC (μmol/L)	Auto. POC / dCO_2	Auto. POC / TOC
PS	Aug	5.3	1.7	27	7.7	760	27	34	166	26	97%	16%
YB	Mar	2.7	1.9	33	5.5	761	36	12	89	9	26%	11%
YB	Nov	1.6	1.5	25	3.1	722	29	4	91	3	11%	4%
JLJ	Mar	3.9	11.7	31	14.2	645	32	46	216	35	109%	16%
XJ	Nov	4.8	1.4	34	13.2	1915	87	52	210	40	46%	19%
The selected sites (average ± SD)		3.6 ± 1.3	3.6 ± 4.0	30 ± 3	8.8 ± 4.3	961 ± 479	42 ± 23	30 ± 19	154 ± 56	23 ± 14	58% ± 39%	13% ± 5%
The whole river (average ± SD)		28.2 ± 34.8	1.4 ± 1.7	12 ± 6	3.0 ± 3.0	1610 ± 825	66 ± 35	43 ± 36	224 ± 107	–	–	–



A typical site (JLJ, an impounded area) showing the dominant control of autochthonous processes on riverine pCO_2. POC increases linearly with Chl a (indicating autochthonous source) and pCO_2 decreases exponentially, unlike the majority of other sites. This is due probably to its specific hydrological regime (b). One single month (September) accounted for > 40% of the annual discharge and > 95% of the annual sediment load during the study year (2014–2015), whereas water and sediment flow in other months were generally low (CWRC, 2014).

4. Conclusion

- Channel heterotrophic respiration comprises an important source of riverine supersaturated CO_2 as indicated by the correlations between pCO_2 and river organic carbon and the negative relationship between pCO_2 and dissolved O_2.
- Essential benthic and/or lateral transport of soil-derived CO_2 must present. However, to put these major processes on accurate scale needs further research.
- pCO_2 can be significantly drawn down in nutrient-rich impounded areas. However, terrestrial and heterotrophic processes still dominate the pCO_2 biogeochemistry in the increasingly impounded river system.

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