Impacts of anthropogenic water regulation on global riverine dissolved organic carbon transport

Yanbin You[1,2], Zhenghui Xie[1,2*] (zxie@lasg.iap.ac.cn), Binghao Jia[1*] (bhjia@mail.iap.ac.cn), Yan Wang[3]

1.LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029, China
2.University of Chinese Academy of Sciences, Beijing 100049, China
3.Nanjing Hydraulic Research Institute, Nanjing 210029, China

§ 1 Abstract

Anthropogenic water regulation activities, including reservoir interception, surface water withdrawal, and groundwater extraction, alter riverine hydrologic processes and affect dissolved organic carbon (DOC) export from land to rivers and oceans. In this study, schemes describing soil DOC leaching, riverine DOC transport, and anthropogenic water regulation were developed and incorporated into the Community Land Model 5.0 (CLM 5.0) and the River Transport Model (RTM). Three simulations by the developed model were conducted on a global scale from 1981 to 2013 to investigate the impacts of anthropogenic water regulation on riverine DOC transport. The validation results showed that DOC exports simulated by the developed model were in good agreement with global river observations. The simulations showed that DOC transport in most rivers was mainly influenced by reservoir interception and surface water withdrawal, especially in central North America and eastern China.

§ 2 Land surface model with riverine DOC transport and anthropogenic water regulation

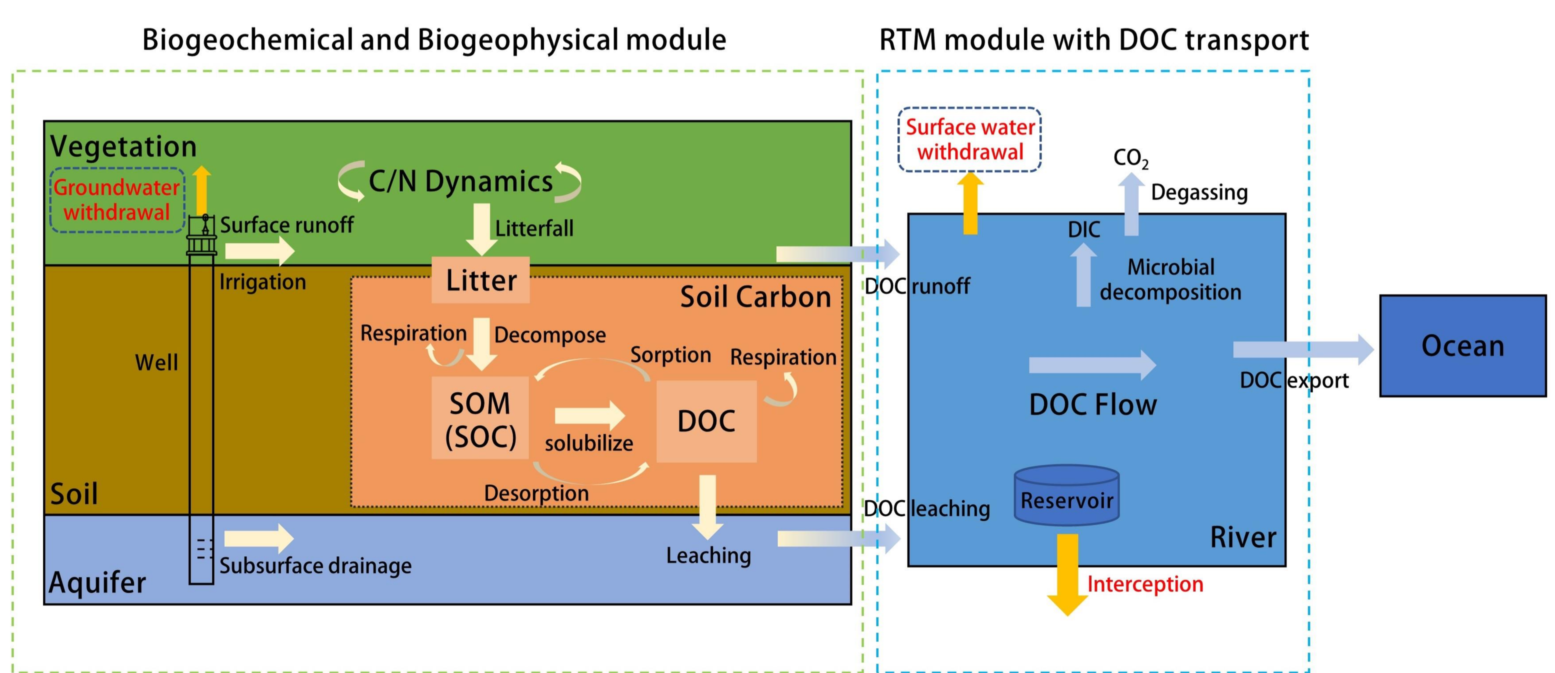

Fig. 1 Schematic diagram of the land surface model with riverine dissolved organic carbon (DOC) transport and anthropogenic water regulation (C: carbon; N: nitrogen; SOM: soil organic matter; SOC: soil organic carbon; DIC: dissolved inorganic carbon).

§ 3 Schemes for the developed model

➢ Soil DOC loss to the river

$$DOC_{loss} = [DOC]Q_* k_{adsorb} - SR$$

where DOC_{loss} denotes the soil DOC runoff or leaching, Q_* denotes the surface runoff or subsurface discharge, [DOC] is the DOC concentration in the soil water solution, k_{adsorb} is the DOC adsorption coefficients, SR is the soil heterotrophic respiration flux of DOC.

➢ Riverine DOC transport

$$\frac{dS_{DOC}}{dt} = F_{DOC}^{in} - F_{DOC}^{out} + R_{DOC} + L_{DOC} - k_{doc} * Q_{10}^{\frac{rt-20}{10}} * S_{DOC}$$

where S_{DOC} is DOC storage within the current grid cell, R_{DOC} and L_{DOC} represent soil DOC runoff and leaching, k_{doc} is the DOC decomposition rate in the river, Q_{10}(=2.0) denotes the temperature coefficient, rt represents the river water temperature, F_{DOC}^{in} is the sum of inflows of riverine DOC from neighboring upstream grid cells, F_{DOC}^{out} is the riverine DOC flux leaving the current grid cell.

➢ Anthropogenic water regulation

$$S_{sw}' = S_{sw} - q_{sw}\Delta t$$
$$S_{gw}' = S_{gw} - q_{gw}\Delta t$$
$$h' = h - \frac{q_{gw}\Delta t}{s}$$

where S_{sw} is the surface water storage, q_{sw} is the rate of surface water intake, Δt denotes the model time step, S_{gw} is unconfined aquifer water storage, q_{gw} is the rate of groundwater pumping, h represents the groundwater table depth, s is the aquifer-specific yield.

§ 4 Experimental design

- ➢ **Study Region**：Global scale
- ➢ **Resolution**：CLM 0.9°×1.25°, RTM 0.5°×0.5°
- ➢ **Atmospheric forcing:** CRU-NCEP v7
- ➢ **CO_2 concentration**：NOAA/Earth System Research Laboratory

	Simulation Period	Surface regulation	Groundwater regulation
CTL	1981-2013	×	×
EXPA	1981-2013	✓	×
EXPB	1981-2013	✓	✓

§ 5 Results 1: Effects of surface water regulation

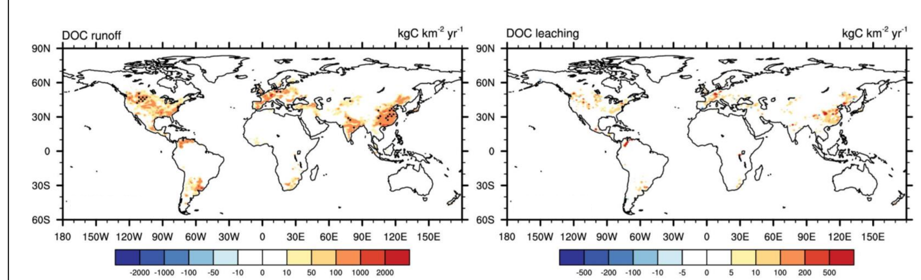

Fig. 2 Spatial distribution of multi-year average changes in soil carbon losses due to surface water regulation.

The hotspots of significantly increased surface DOC runoff were in areas of high agricultural influence, because irrigation directly increasing surface runoff and subsurface runoff, and thus increasing soil DOC losses.

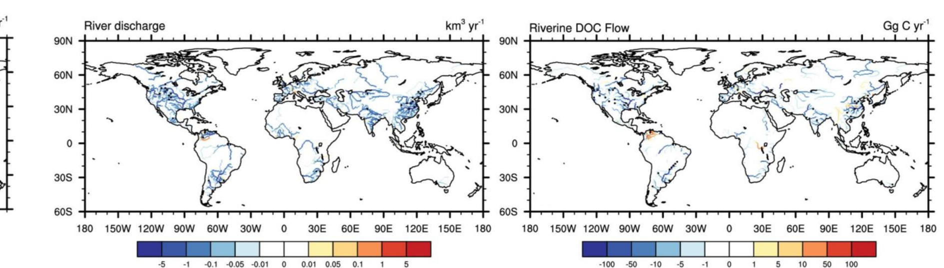

Fig. 3 Spatial distribution of multi-year average changes in river discharge and riverine DOC flow due to surface water regulation.

The combined effects of reservoir interception and surface water withdrawal reduced the discharge and DOC export of most rivers globally, with significant reductions of more than 50 Gg C.

§ 6 Results 2: Effects of groundwater regulation

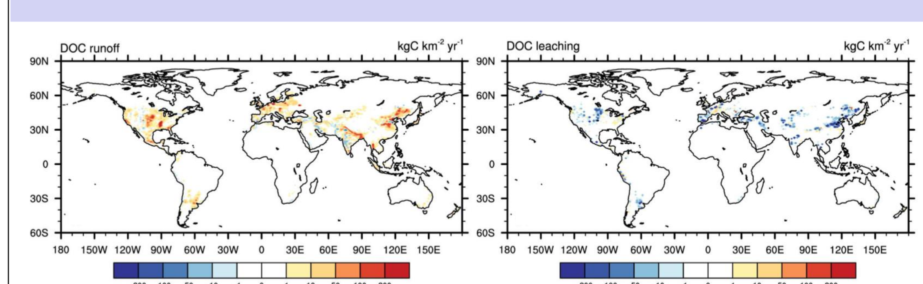

Fig. 4 Spatial distribution of multi-year average changes in soil carbon losses due to groundwater regulation.

Irrigation led to an increase in surface runoff, which led to an increase in DOC runoff.

Extracting water from underground aquifers led to a reduction in subsurface runoff and a consequent reduction in DOC leaching.

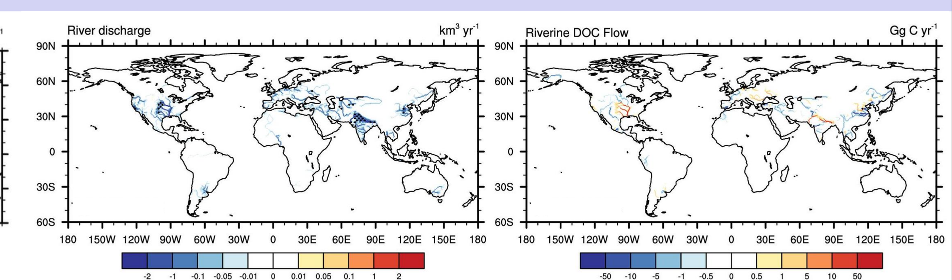

Fig. 5 Spatial distribution of multi-year average changes in river discharge and riverine DOC flow due to groundwater regulation.

River discharge significantly decreased in areas with high groundwater extraction rates, resulting in a decrease in riverine DOC export. DOC export fluxes were increasing in Mississippi River, and Ganges River basins.

§ 7 Results 3: Effects of anthropogenic water regulation

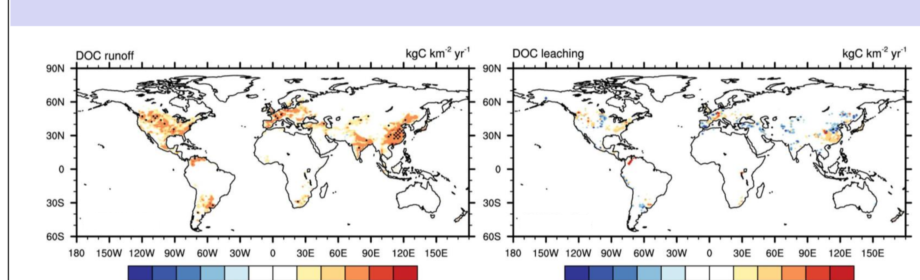

Fig. 6 Spatial distribution of multi-year average changes in soil carbon losses due to anthropogenic water regulation.

Soil DOC runoff increased, especially in northern China and the midwestern United States.

DOC leaching decreased in some river reaches, but not significantly.

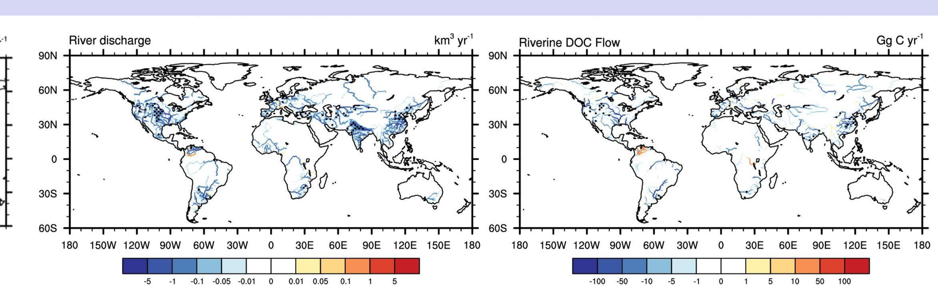

Fig. 7 Spatial distribution of multi-year average changes in river discharge and riverine DOC flow due to anthropogenic water regulation.

DOC export fluxes decreased in most rivers globally, indicating that most rivers globally are mainly influenced by reservoir interception and surface water withdrawal.

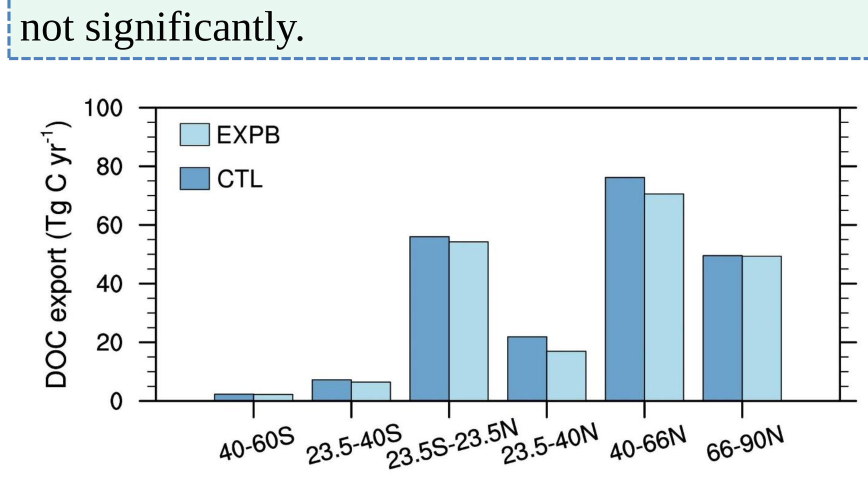

Fig. 8 Latitudinal band distribution of multi-year average DOC export fluxes.

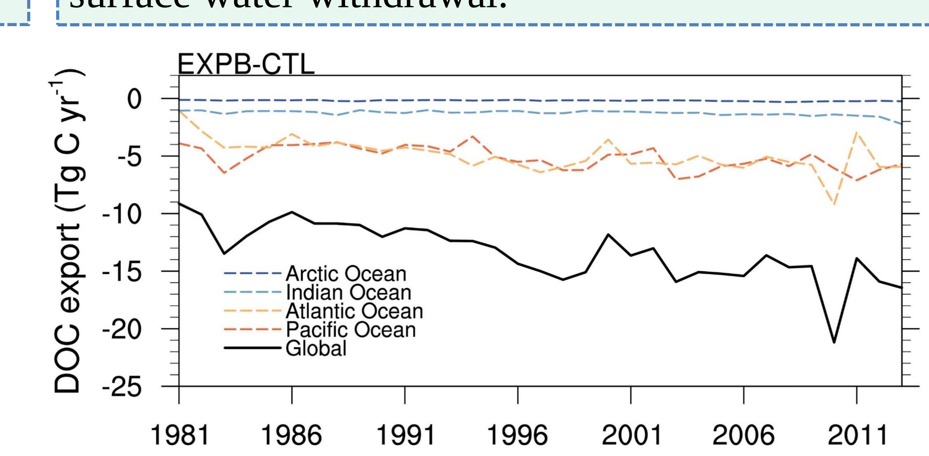

Fig. 9 Interannual variability in the impact of anthropogenic water regulation.

Global DOC export flux was reduced by 13.36 Tg C yr^{-1} compared to the case with no human regulation. The greatest impact concentrated in the subtropical and temperate regions of the Northern Hemisphere (23.5–66°N).

Anthropogenic water regulation reduced global riverine carbon fluxes, and the reduction in DOC fluxes also intensified over time, from –9.13 Tg C yr^{-1} to –16.45 Tg C yr^{-1}, especially in the Pacific and Atlantic Ocean regions.

§ 8 Conclusions

- This study has developed schemes that consider soil and riverine DOC dynamics and anthropogenic water regulation activities and has incorporated them into the land surface model.
- DOC transport in most rivers globally is mainly influenced by reservoir interception and surface water withdrawal.
- Global riverine DOC flux transport to the ocean decreased by an average of 13.36 Tg C per year due to anthropogenic water regulation activities, and the decrease in DOC flux became more pronounced with time, from -9.13 Tg C yr^{-1} (4.83 %) in 1981 to –16.45 Tg C yr^{-1} (6.20 %) in 2013, especially in the Pacific and Atlantic Ocean regions.

Reference: You, Y., Xie, Z., Jia, B., et al., 2023: Impacts of anthropogenic water regulation on global riverine dissolved organic carbon transport, Earth Syst. Dynam.