$^{224}Ra/^{228}Th$ disequilibrium in sediments of Lake Taihu: Implications of nitrogen fluxes across the sediment–water interface

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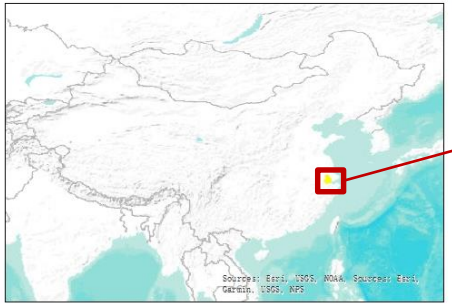
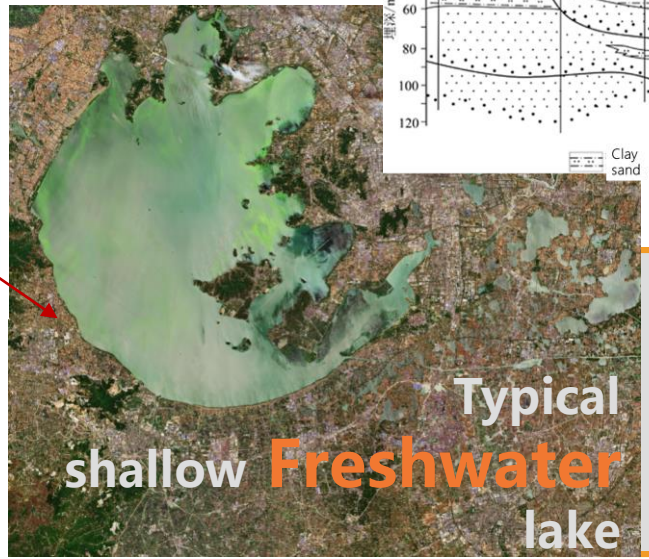
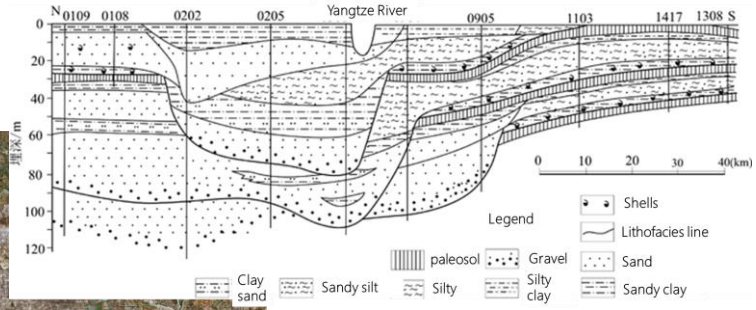
About Lake Taihu



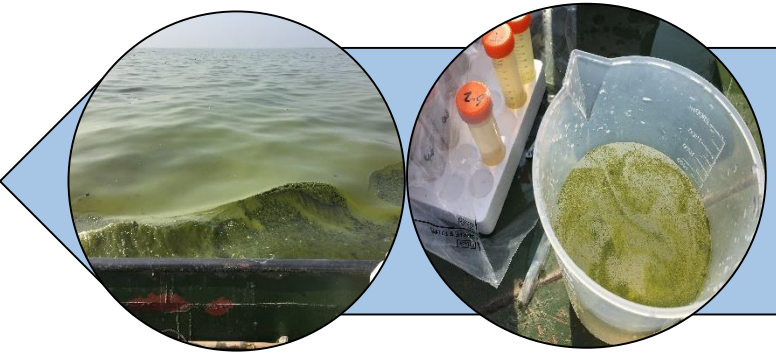




Location

Locates near the Yangtze River Delta, one of the most industrialized and urbanized area in China.

- Water area: 2338.1 km^2
- Average depth: 1.9 m, with flat bottom
- Surrounded by complex, high-density set of surface water networks



➢ **Importance**

Supply drinking water for the cities nearby, also have high value in tourism, aquaculture, fisheries, and navigation.

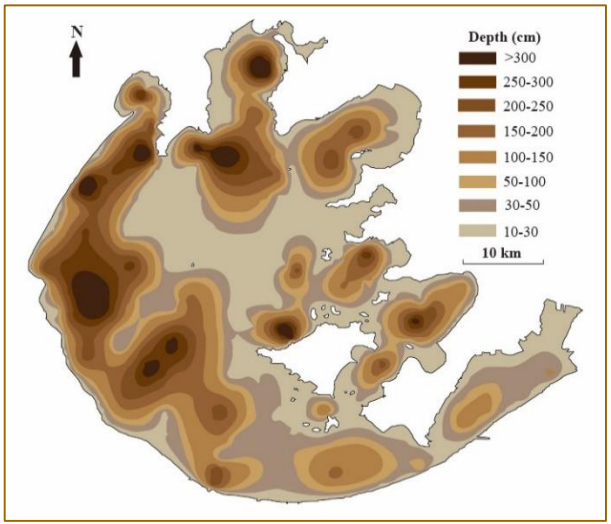
➢ **Problems**

Suffer from serious eutrophication and vicious algal bloom.

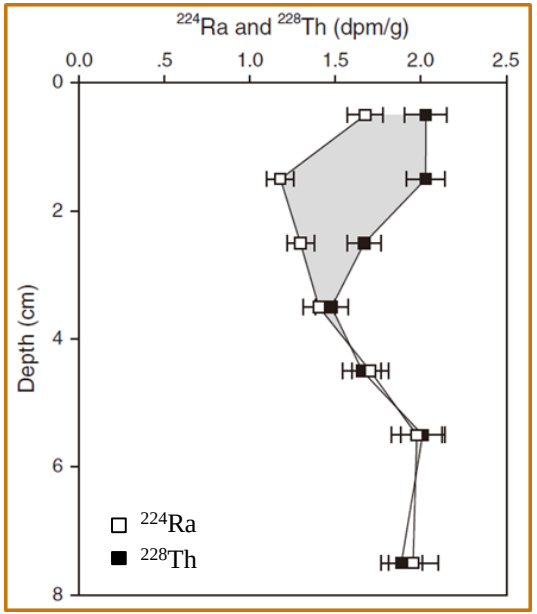
(Baoqiang Qin,2007; Xitao Zhao, 2017; The health status report of Taihu lake, 2017; Hydrogeology report of Suzhou City, 2000)

Sediments, benthic fluxes and ^{224}Ra-^{228}Th disequilibrium

◎ Distribution of soft sediment (silty clay) in Lake Taihu.



- Significance of sediments: sediments can be "sources" and "sinks" of nutrients and pollutants, and have great influences on the eutrophic state and ecosystem balance of the aquatic environment.
- Dynamics of benthic fluxes: physically generated by concentration gradients, but it could be enhanced by disturbance from external forces.
- Bioirrigation: process of burrow flushing by burrow-dwelling animals, and it could enhance the benthic flux rate by orders of magnitude.



◎ ^{224}Ra-^{228}Th disequilibrium in marine sediment.

◆ ^{224}Ra and ^{228}Th: In sediments, ^{224}Ra (half-life=3.66 d) is continuously produced via alpha decay by its parent nuclide ^{228}Th (half-life=1.91 yr) and a steady state could be reached without disturbance. While ^{224}Ra-^{228}Th disequilibrium may occur in near-surface sediments. The fraction of ^{224}Ra are released to the interstitial water and migrate across the sediment–water interface into the overlying water as the consequence of the multiple processes that operate at the sediment–water interface. The extent of ^{224}Ra deficit will lead to the insights of benthic flux and material transport.

(Cai et al., 2012; Porcelli, 2008; Zhu et.al., 2006;)

Aims of this Research

Radioisotopes tracers

Take the leading attempt to apply isotopic tracers ^{224}Ra-^{228}Th in a large freshwater lake.

Benthic fluxes

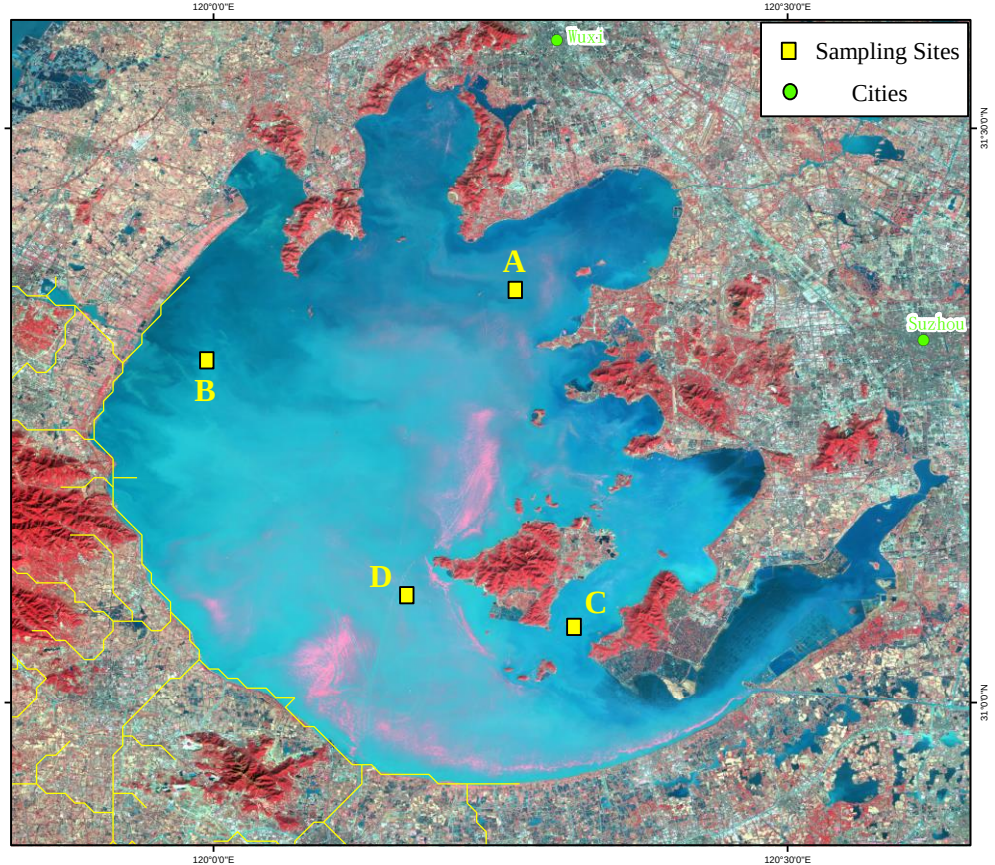
Identify its dynamic framework and influencing factors by ^{224}Ra-^{228}Th disequilibrium.

Nutrients input

Explore the potential contributions of benthic fluxes to the eutrophic lake.

Field sampling

16-19th of December, 2018

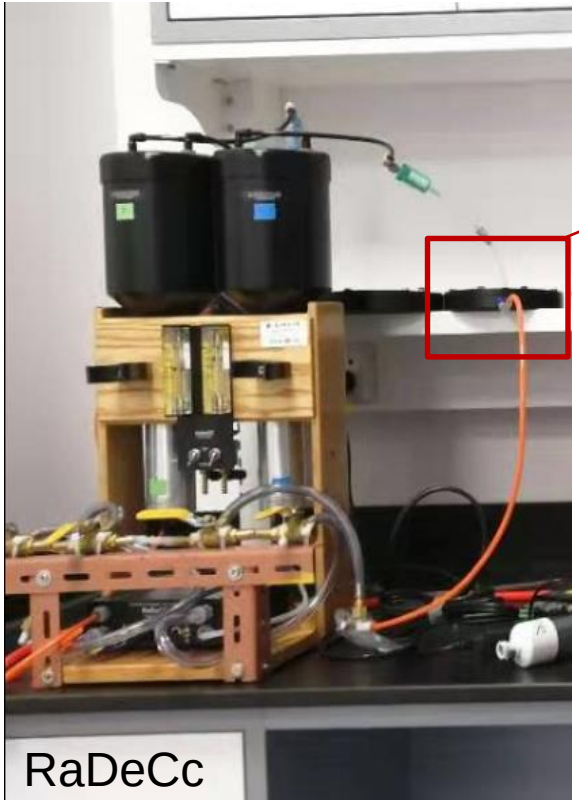


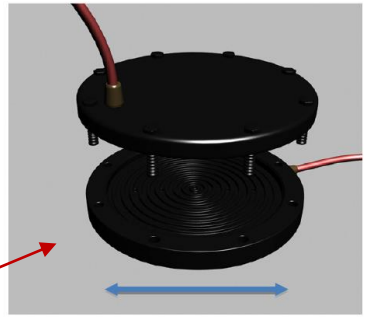
- Surface sediment cores (20-30 cm) were collected by cylindrical sediment sampler, and the sediment samples were taken every 2 cm.

Laboratory analysis

$^{224}Ra/^{228}Th$ and nutrients

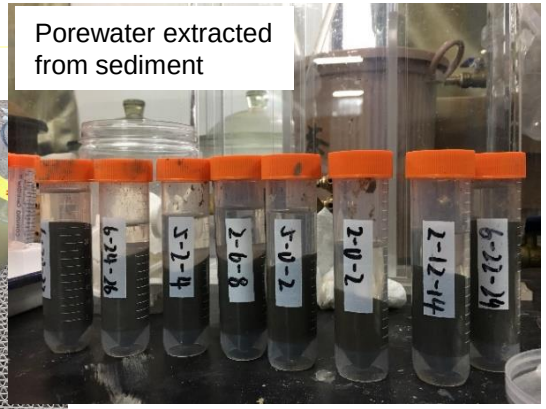
^{224}Ra and ^{228}Th in sediments were determined following the instruction described in Cai et al. (2012).



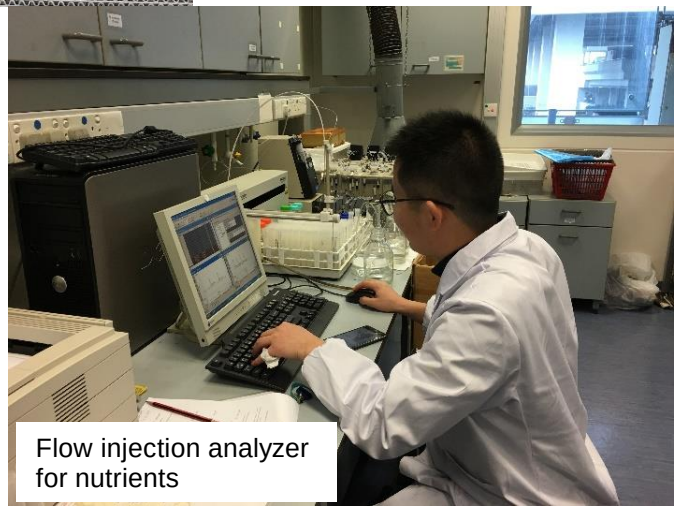


Sediment samples processing

Porewater extracted from sediment

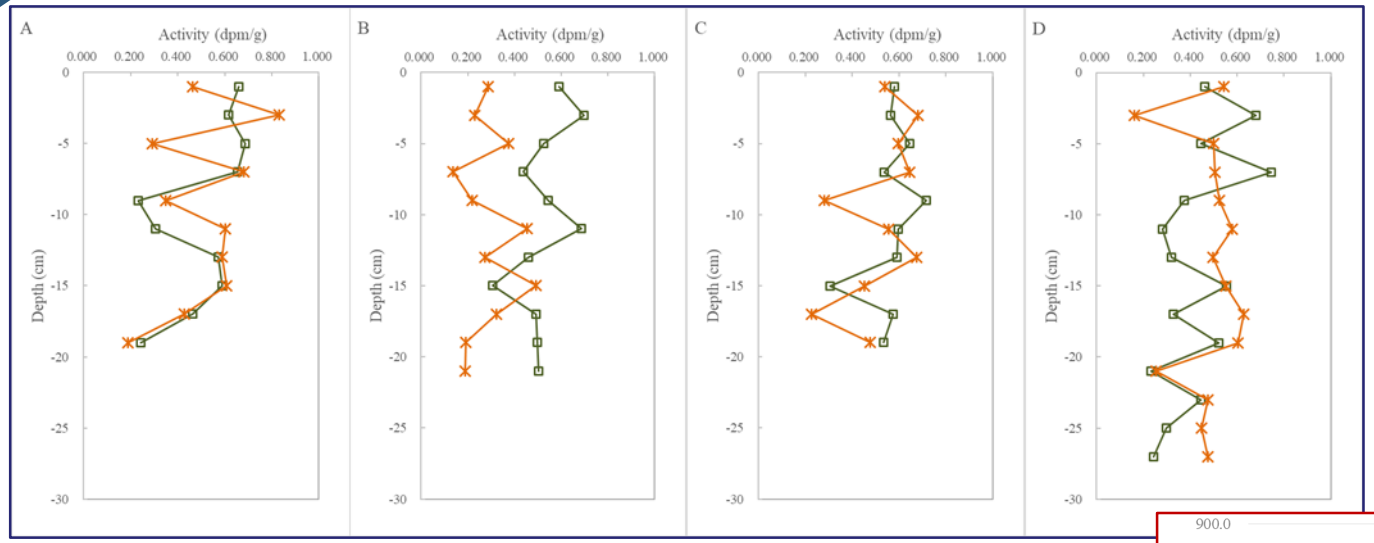


Samples to be tested



Flow injection analyzer for nutrients

Results of ^{224}Ra-^{228}Th and nutrients

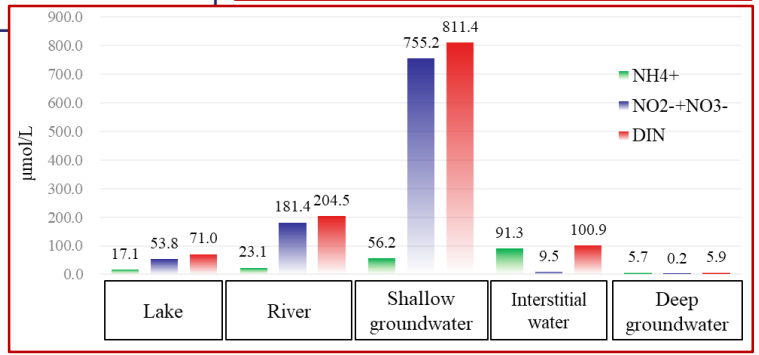


01 Profiles of ^{224}Ra and ^{228}Th in sediments — ^{224}Ra — ^{228}Th

- The activities of ^{224}Ra and ^{228}Th in sediments from different areas in Lake Taihu are within the similar ranges.
- At most sampling sites, the secular equilibrium between ^{224}Ra and ^{228}Th is not reached at the sampling depth.

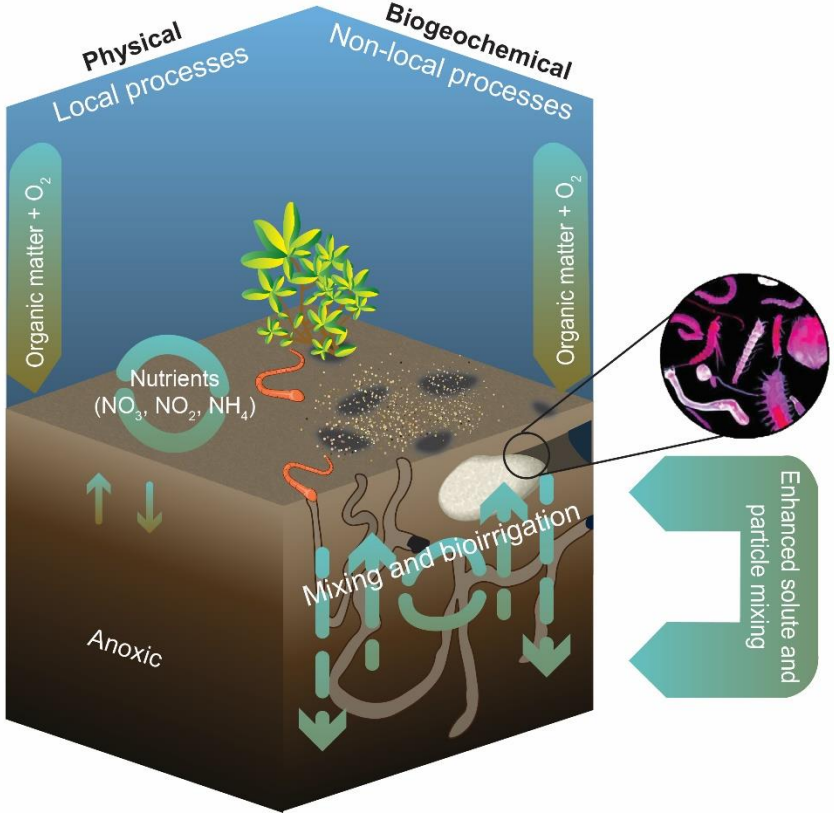
02 DIN distribution in different types of water

- Sediment interstitial water is more enriched with nutrients than that in lake water, and could be another potential nutrient source together with river and shallow groundwater.
- Ammonium is the leading type of dissolved inorganic nitrogen (DIN) due to the relative anoxic environment.



Benthic fluxes of ^{224}Ra

Early diagenetic equation



$$\frac{\partial \varphi C}{\partial t} = \frac{\partial}{\partial z}\left(D_S \varphi \frac{\partial C}{\partial z}\right) - \frac{\partial (v \varphi C)}{\partial z} + \alpha \varphi \left(C_{flush} - C\right) + R$$

D_S——diffusion coefficient, α——bioirrigation coefficient,

R——the net rate of production,

C——the solute concentration in the bulk sediment,

C_{flush}——the flushing concentration of the solute,

φ——porosity, z——depth, v——advection velocity.

(Snelgrove et al., 2018, Meile et al., 2001)

Benthic fluxes of ^{224}Ra

^{224}Ra deficit in sediments of Lake Taihu

$$\frac{\partial[\rho_s(1-\varphi)^{224}Ra]}{\partial t}=\frac{\partial}{\partial z}\left[\frac{D_s}{K+1}\times\frac{\partial(\rho_s(1-\varphi)^{224}Ra)}{\partial z}\right]+\alpha\rho_s(1-\varphi)\left(^{224}Ra_{flush}-{}^{224}Ra\right)+\lambda_{224}\rho_s(1-\varphi)(^{228}Th-{}^{224}Ra)$$

ρ_s —— density of natural sediment

K—— dimensionless adsorption constant linked to the distribution coefficient of ^{224}Ra by the relation $K=K_d\times\left(\frac{\rho_s(1-\varphi)}{\varphi}\right)$

Simplification

- Advection is negligible: the lake bed is flat and sediments are physically and chemically homogeneous.
- Diffusion is negligible: K of ^{224}Ra in Lake Taihu is calculated to be 11863.4, which leads to a minor effect from diffusion.
- Wind-induced disturbance is negligible: the wind speeds are mostly lower than the threshold (4 m s^{-1}) that could cause sediment resuspension in Lake Taihu when sampling.

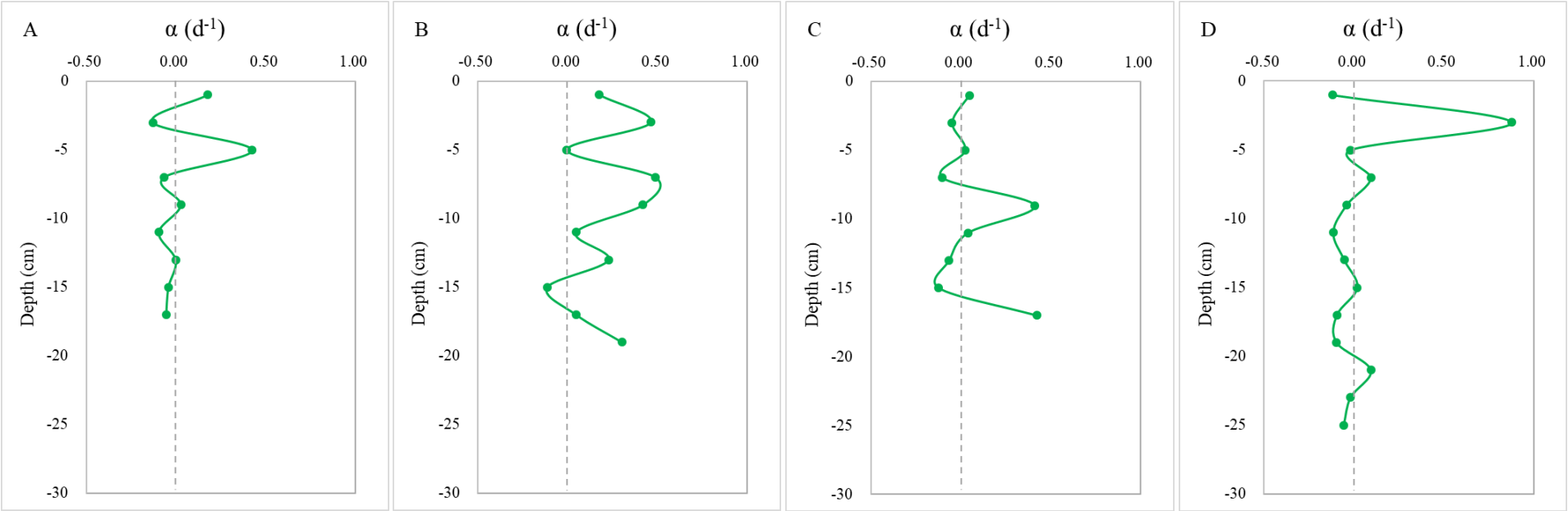
For ^{224}Ra deficit in sediments of Lake Taihu:

$$\frac{\partial^{224}Ra}{\partial t}=\alpha\left(^{224}Ra_{flush}-{}^{224}Ra\right)+\lambda_{224}(^{228}Th-{}^{224}Ra)$$

(Qin et al.,2003, WU et al., 2013, Yang Dingtian et al.,2008, Krishnaswami et al., 1982,)

Benthic fluxes: $^{224}Ra/^{228}Th$

Bioirrigation coefficient α



- α is peaked at specific depth, and the vertical heterogeneity rather than the monotonic change reflect the great fluctuation of the bio-activities along the profile.
- The negative α occurs when the flushing of burrow structures is incomplete or infrequent.

Comparison

α and nutrients input

0.019~0.876 d^{-1}

in Lake Taihu

This study

0.086~2.592 d^{-1}

in marine sediment

(Meile et al., 2001)

Nutrients input in Lake Taihu:

Lacustrine groundwater discharge

Discharge rate:
2.50~3.03 mm d^{-1}

DIN input:
6.63~8.04 × 10^4 kg d^{-1}

(Shi et al., 2020, unpublised)

River

Quantity:
2.34 × 10^7 m^3 d^{-1}

DIN input:
6.70 × 10^4 kg d^{-1}

(Yearly report of Lake Taihu, 2018)

Benthic flux

Diffusion:
2.26 × 10^4 kg d^{-1} (57.9%)

Bioirrigation:
1.64 × 10^4 kg d^{-1} (42.1%)

(This study)

Conclusions

Potential nutrient sources

Nutrients are over-loaded in porewater of sediments, and could be related to the eutrophication of Lake Taihu by benthic fluxes.

Benthic fluxes in Lake Taihu

Bioirrigation is one of the significant dynamic of benthic fluxes in Lake Taihu, and the coefficient α is estimated to range within 0.019~0.876 d^{-1}. The DIN input from benthic fluxes is estimated to have the same magnitude with that from rivers and lacustrine groundwater discharge.

Radioactivity isotopes of $^{224}Ra/^{228}Th$

^{224}Ra and ^{228}Th are instructional and effective integrating methods to similar studies in freshwater lakes elsewhere.

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