Modelling of sedimentation-regulated methane ebullition from reservoirs

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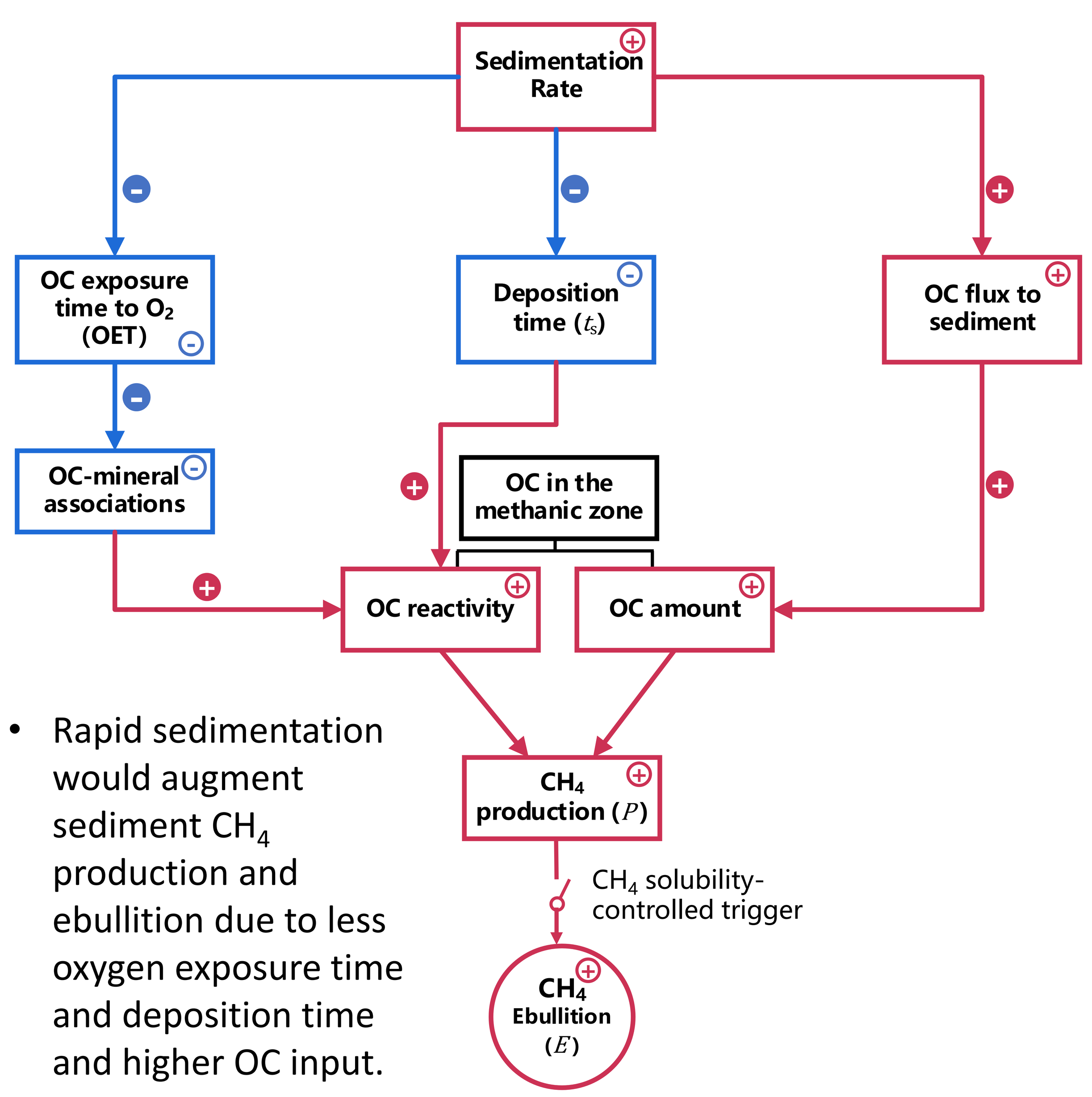
Introduction

- Global reservoirs emit CH_4 at 606.5 Tg CO_2 Eq. per year, accounting for 78.5% of total GHG emissions. Ebullition is a major pathway of CH_4 release, accounting for 78-88% of global reservoirs CH_4 emissions.
- The global reservoir sediment sequestration has surged to 65 Gt yr^{-1} in 2010 from 2.8 Gt yr^{-1} in 1950, burying 58 Tg C yr^{-1} of organic carbon and fueling CH_4 production and emissions.
- Field observations and laboratory experiments indicate that CH_4 production and ebullition increases disproportionately to reservoirs sedimentation rate.
- In this study, by introducing the intrinsic link between sedimentation and CH_4 production, and hence ebullition, a novel mechanistic reservoir CH4 model was developed to quantify ebullition from reservoirs.

Mechanisms

Regulatory mechanisms of sedimentation on CH_4 production and ebullition



- Rapid sedimentation would augment sediment CH_4 production and ebullition due to less oxygen exposure time and deposition time and higher OC input.

Mathematical Model

CH_4 dynamics in sediment

$$\frac{\partial \phi c_s}{\partial t} = \frac{\partial}{\partial z}\left(D_s \frac{\partial c_s}{\partial z}\right) + \phi v_s \frac{\partial c_s}{\partial z} + P - E$$

- CH_4 production

$$P = R_c s_{oc} Q_{10}^{(T_s - T_r)/10}$$

$$R_c = \begin{cases} 0 & -z_o < z \le 0 \\ R_0 \left(\frac{v_s}{v_0}\right)^{\beta} \exp(-k\tau_s) & -z_s \le z \le z_o \end{cases}$$

$$\tau_s = |z|/v_s$$ * v_s:sedimentation rate; τ_s:deposition time

- CH_4 bubble formation

$$E = \mathcal{H}(c_s - \alpha_e c_{cr}) \cdot \phi\eta(c_s - \alpha_e c_{cr})$$

CH_4 dynamics in water

$$\frac{\partial c_w}{\partial t} = \frac{\partial}{\partial z}\left(D_e \frac{\partial c_w}{\partial z}\right) - S_o$$ *S_o:CH_4 oxidation

CH_4 emissions

- CH_4 diffusion

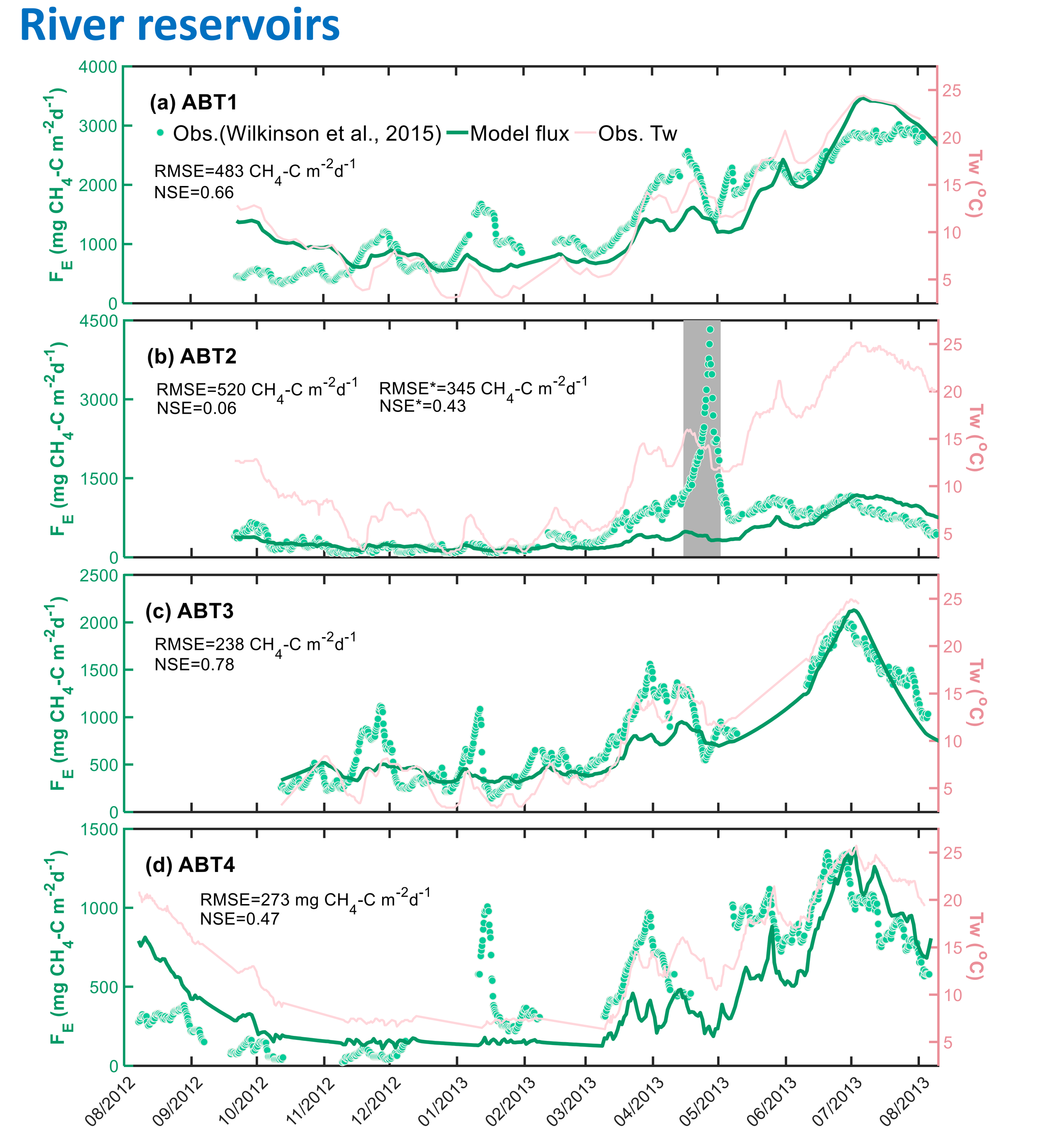
$$F_D = k_T\left(c_w - k_H p_{CH_4}^{atm}\right) M_{CH_4-C}$$

- CH_4 ebullition

$$F_E = (1-\xi)\int_{-z_s}^{0} E \, dz \cdot M_{CH_4-C}$$

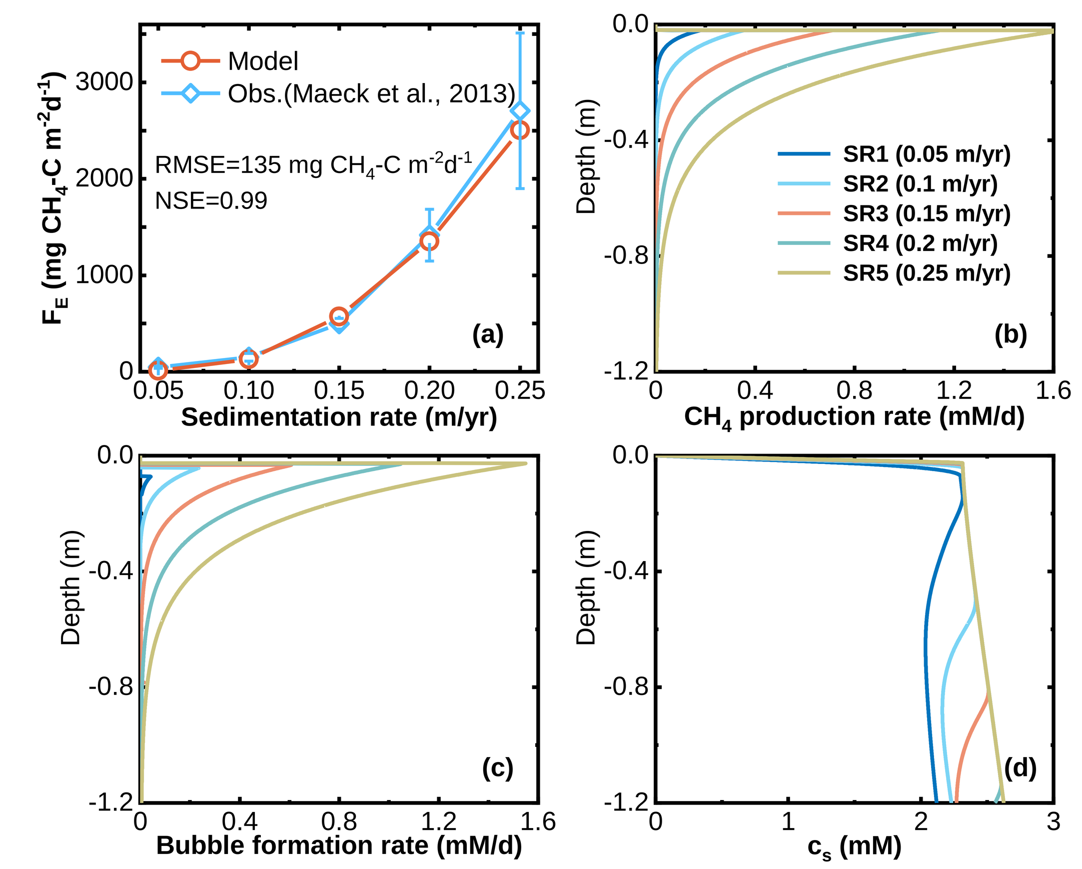
Results

Seasonal dynamics of CH_4 ebullition in the Saar River reservoirs



Results

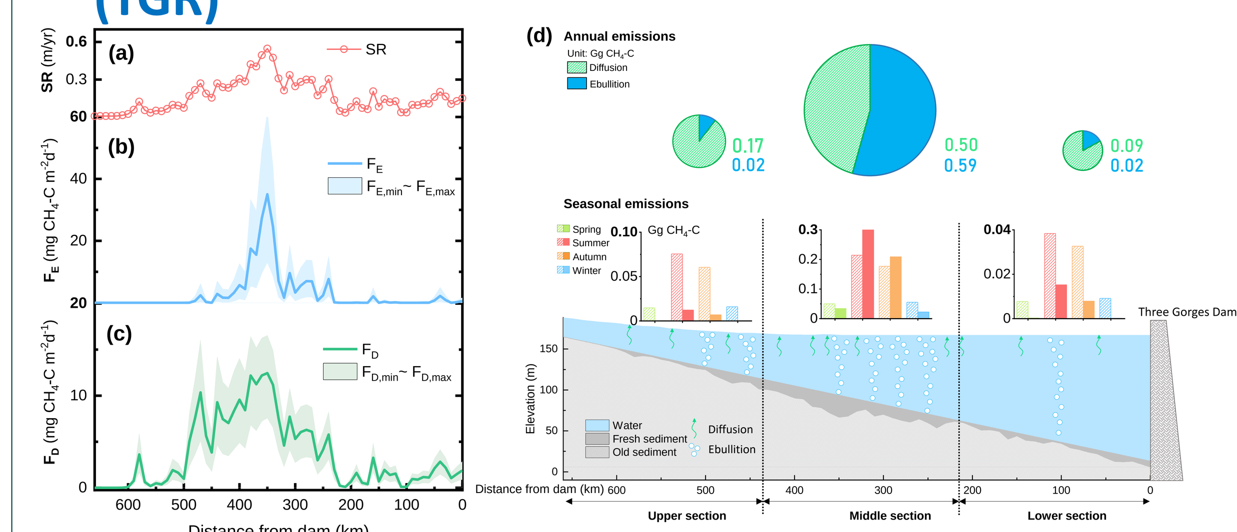
CH_4 dynamics at different sedimentation rates



- CH_4 ebullition increases exponentially with sedimentation rate.
- Sediment CH_4 production is the primary control for CH_4 bubble formation.
- Under porewater CH_4 supersaturation, the majority of the increased CH_4 production, resulting from an elevated sedimentation rate, is released via ebullition.

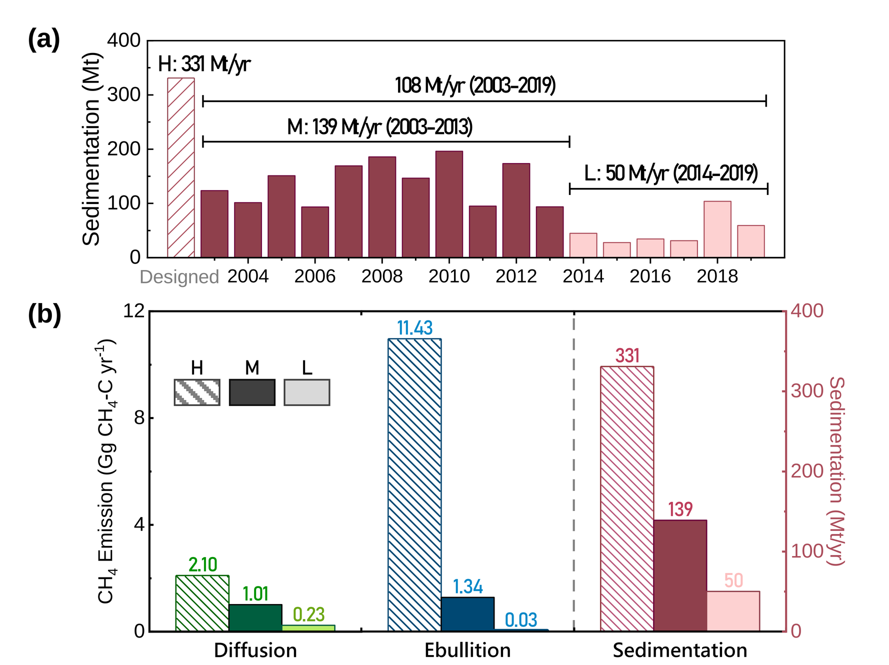
Model Application

CH_4 emissions from the Three Gorges Reservoirs (TGR)



* SR: Sedimentation rate

CH_4 emissions from the TGR in different sedimentation scenarios

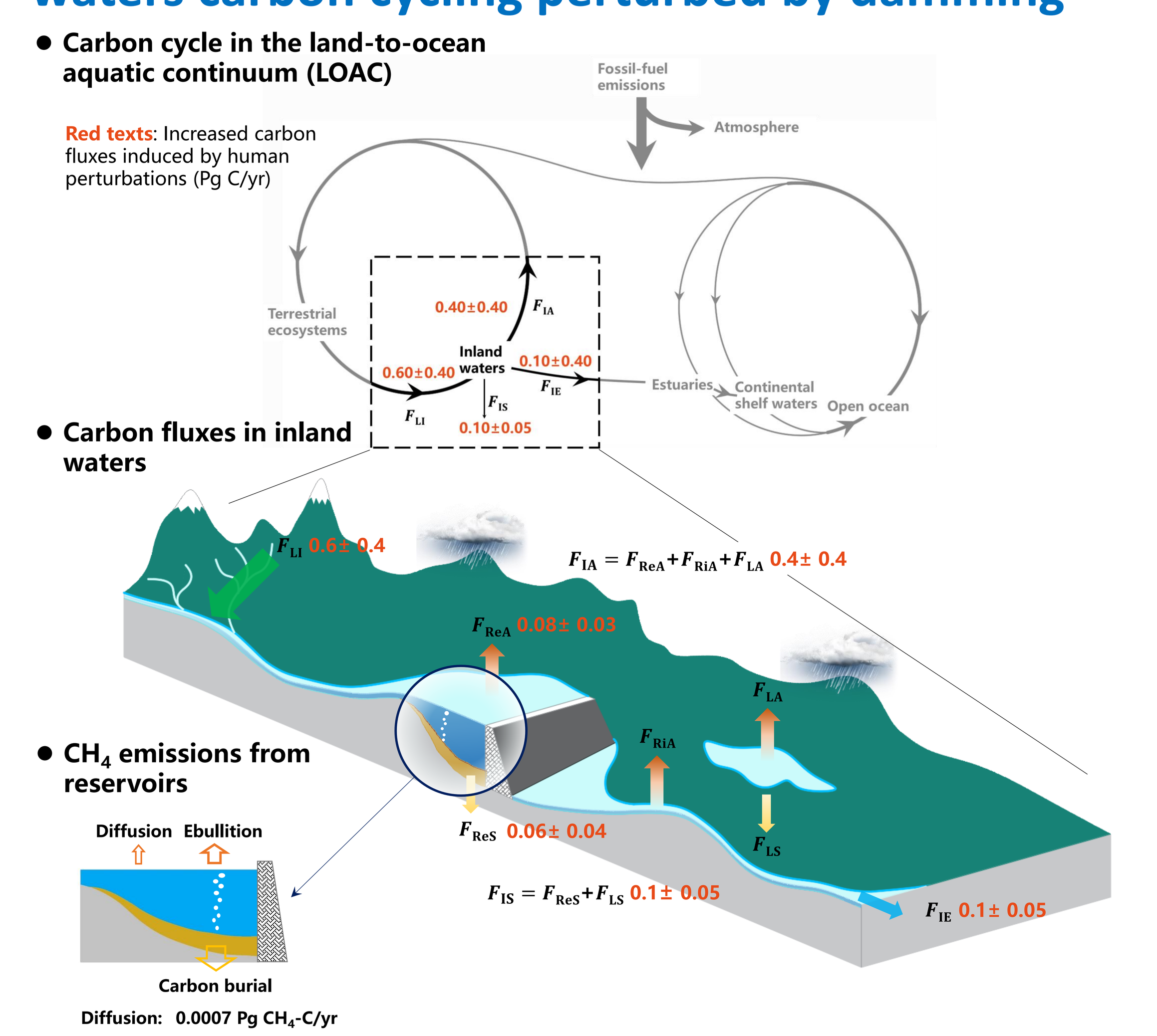


Environmental Implications

The role of the TGR's CH_4 ebullition and carbon burial in the Yangtze River carbon cycling

- Since dam closure, the TGR trapped 108 Mt yr^{-1} sediments and buried 1048 Gg C yr^{-1}, fueling CH_4 ebullition of 0.63 Gg CH_4-C yr^{-1}. The TGR's ebullition could account for 23.3% of CH_4 emissions from the Yangtze River (2.7 Gg CH_4-C yr^{-1}).
- The TGR could bury 1048 Gg C yr^{-1}, which explains 64% of the decreased carbon emissions (1636.7 Gg C yr^{-1}, Ni et al., 2022) from the downstream Yangtze River in term of carbon budget.
- The sedimentation-regulated CH_4 ebullition from the TGR could, to some extent, reflect the impacts of the reservoir carbon burial on the Yangtze River carbon cycling.

The role of reservoirs ebullition in global inland waters carbon cycling perturbed by damming



Conclusions

- Excessive CH_4 production is required to induce porewater CH_4 super-saturation and trigger bubble formation. Sedimentation can regulate reservoir CH_4 ebullition by influencing CH_4 production.
- By trapping most of the sediments from upstream, the TGR experienced a surge in CH_4 emission from 0.17 to 1.38 Gg CH_4-C yr^{-1} after impoundment, mainly via ebullition (0.63 Gg CH_4-C yr^{-1}).

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