Flow patterns and water mixing in a river confluence

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Abstract

Confluences are common components of all riverine systems. Existing studies mostly focus on the specific confluence hydrodynamics influenced by confluence planform geometry, momentum ratio and bed concordance/discordance, but there are few research on the density flow, which could alter the fluvial processes that affect mixing within confluences, especially combined with the impacts of reservoir regulation. In this study, we investigate the hydro-thermodynamic processes at a major confluence in the Yangtze River using a 3D numerical model. The results show that reservoir regulation alters flow patterns in the confluence zone significantly in both horizontal and vertical planes. The density difference leads to changes in the hydro-thermodynamic processes, especially in combination with the reservoir regulation. More importantly, it is found that the combined effect of reservoir regulation and thermal buoyancy alters the flow structure considerably in the confluence zone, and modifies the water transport mode in the mainstream.

Scientific Questions

How are the flow patterns, as well as the mixing processes, in the confluence are influenced by the density differences and reservoir regulation, respectively?

How are both lateral and vertical mixing patterns are influenced by the changed hydrodynamics?

3D Hydro-Thermodynamic Model

Model configurations: Delft3D-FLOW is used to simulate the hydro-thermodynamic processes in Jialing River and Yangtze River confluence.

- Hydrostatic and Boussinesq assumptions
- Grid cell size: 15 m×15 m×0.35 m
- Grid cell number: 1.89 ×10^6
- Eddy viscosity

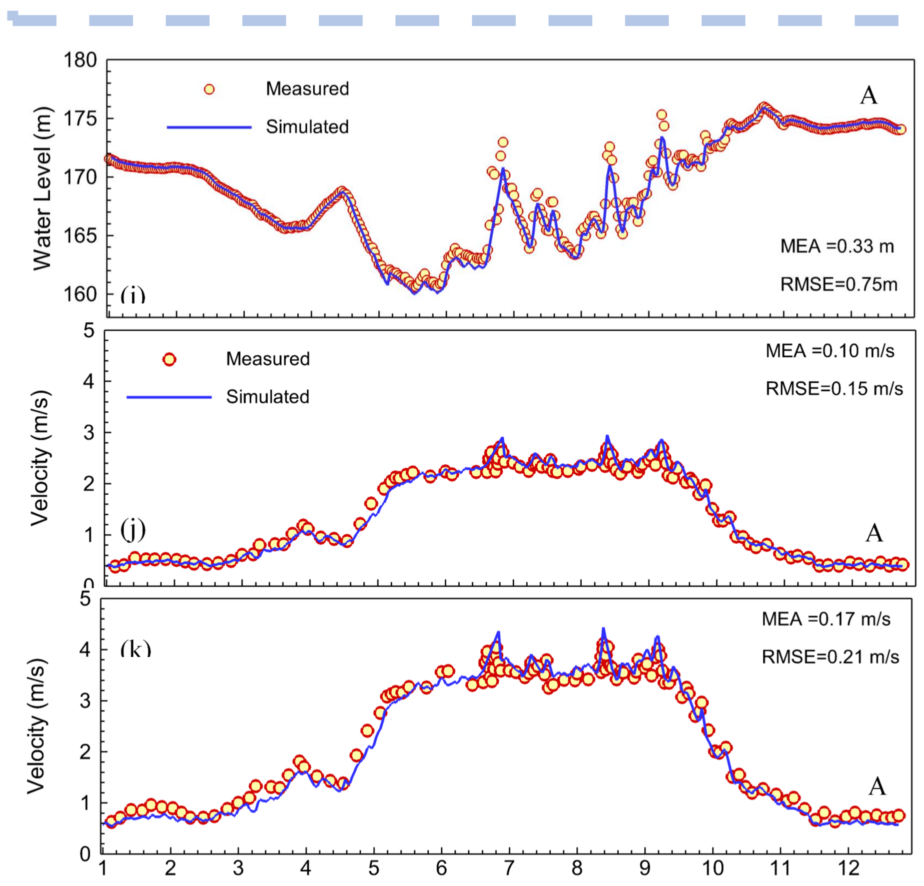
$$\nu_H = \nu_{HLES} + \nu_V + \nu_H^B$$

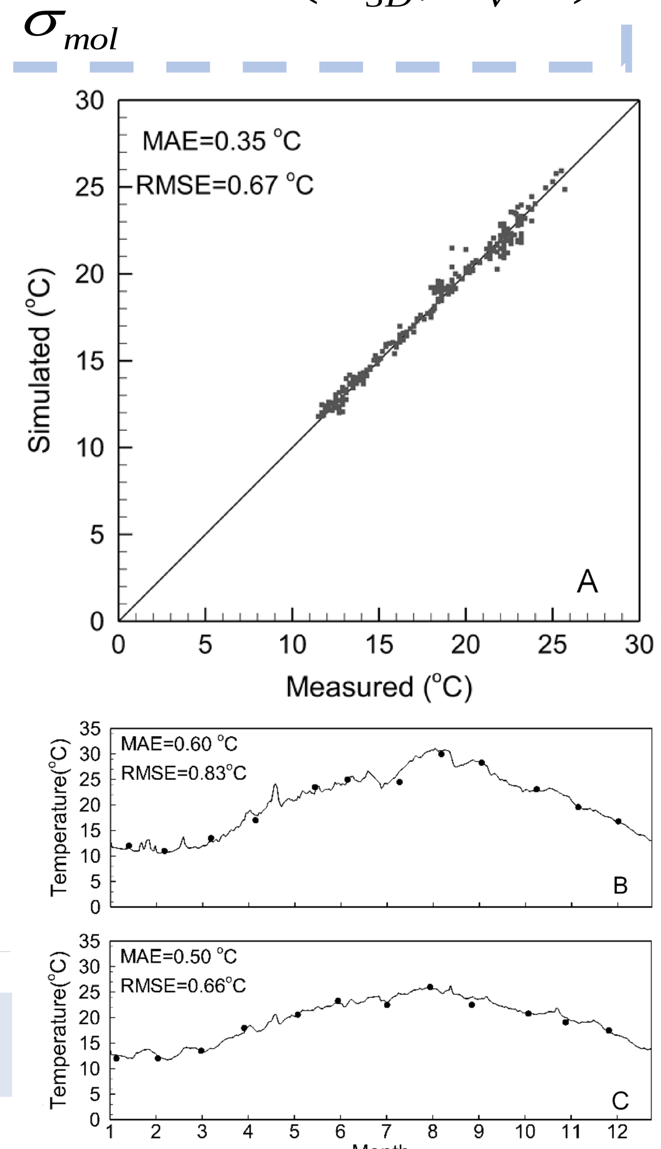
$$\nu_V = \nu_{mol} + \max(\nu_{3D}, \nu_V^B)$$

- Diffusion coefficient

$$D_H = D_{SGS} + D_V + D_H^{back}$$

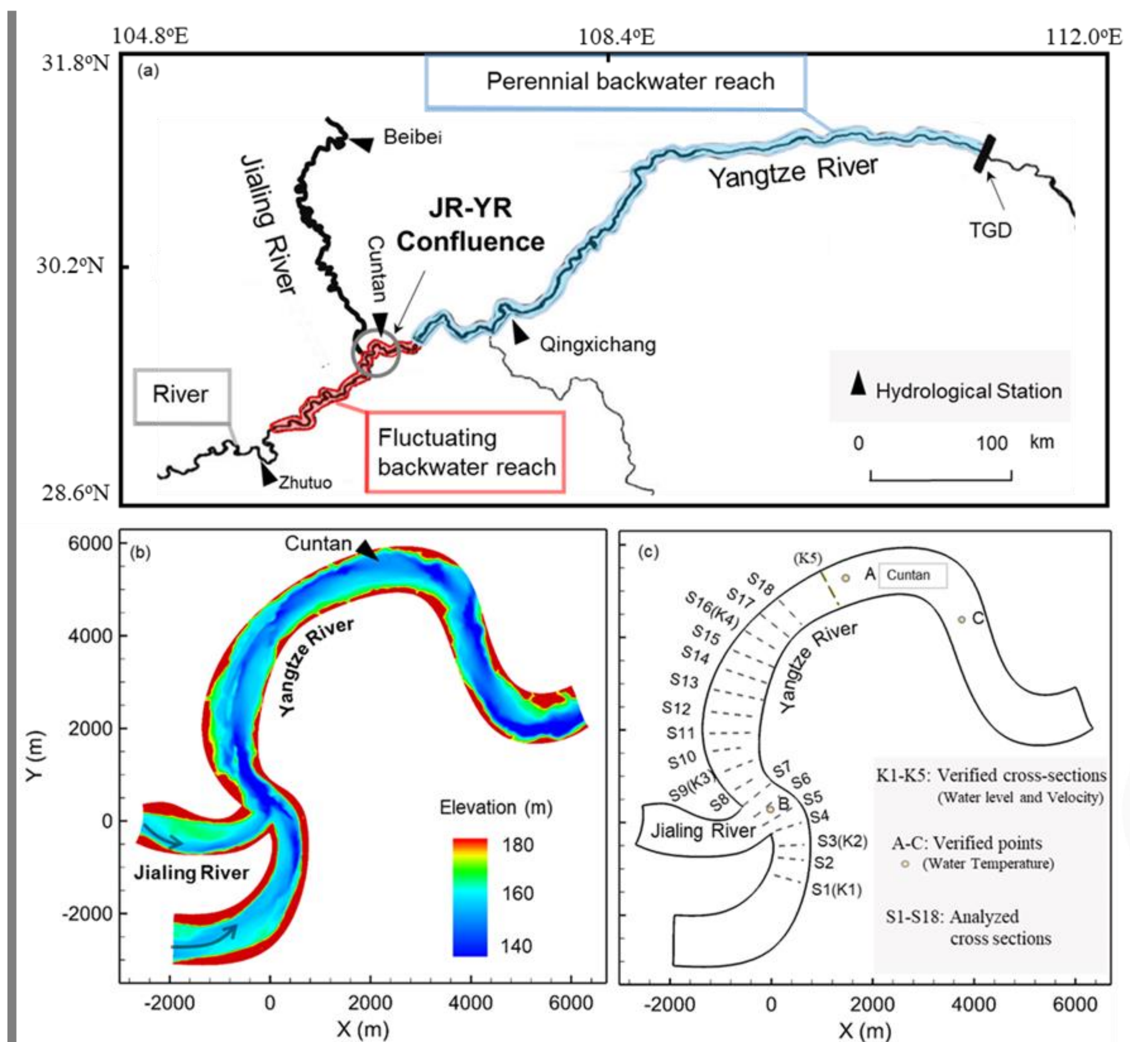
$$D_v = \frac{\nu_{mol}}{\sigma_{mol}} + \max(D_{3D}, D_V^{back})$$





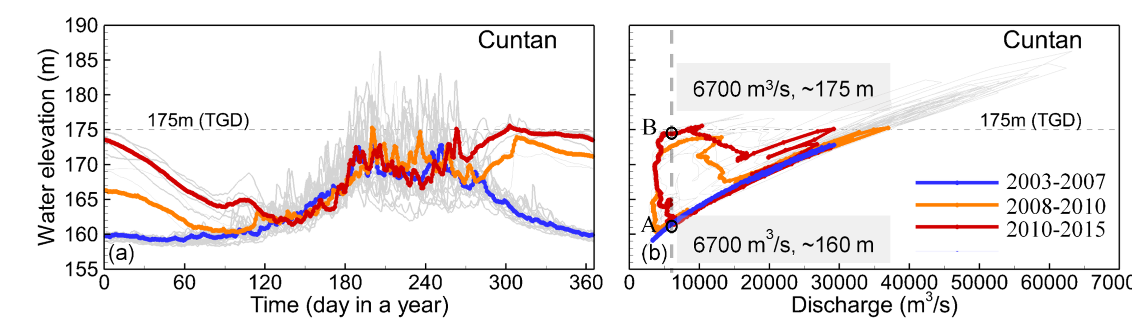
Model Validation and Calibration

Study Area

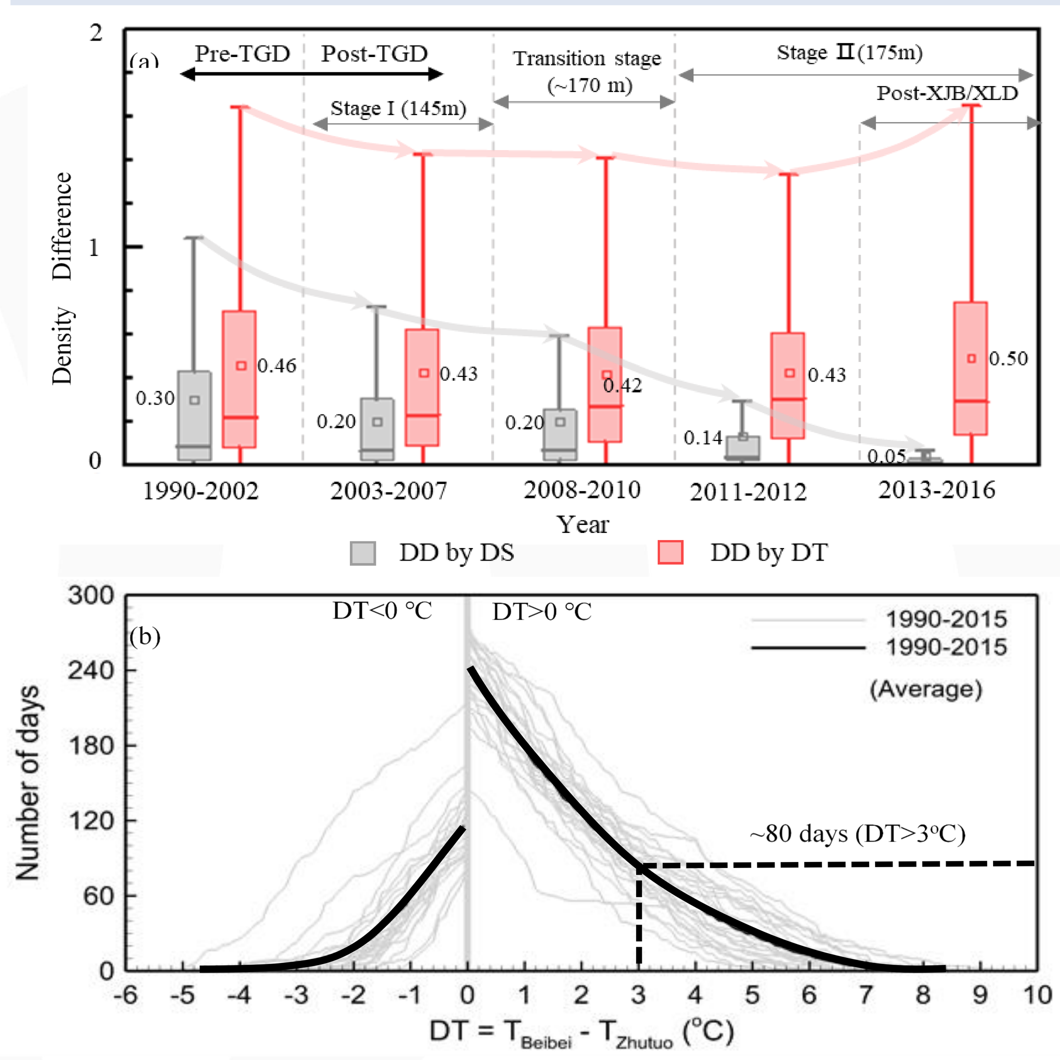


Study area: (a) The Three Gorges Reservoir in the upper Yangtze River. The blue line represents the perennial backwater reach at 145 m, the red line represents the fluctuating backwater area. (b) The confluence bathymetry. (c) The computational domain and the cross sections where the solution is analyzed.

Confluence Hydrology



Hydrological condition: the seasonal variation in water level is shown in (a) and the relationship between the water level and discharge is shown in (b).

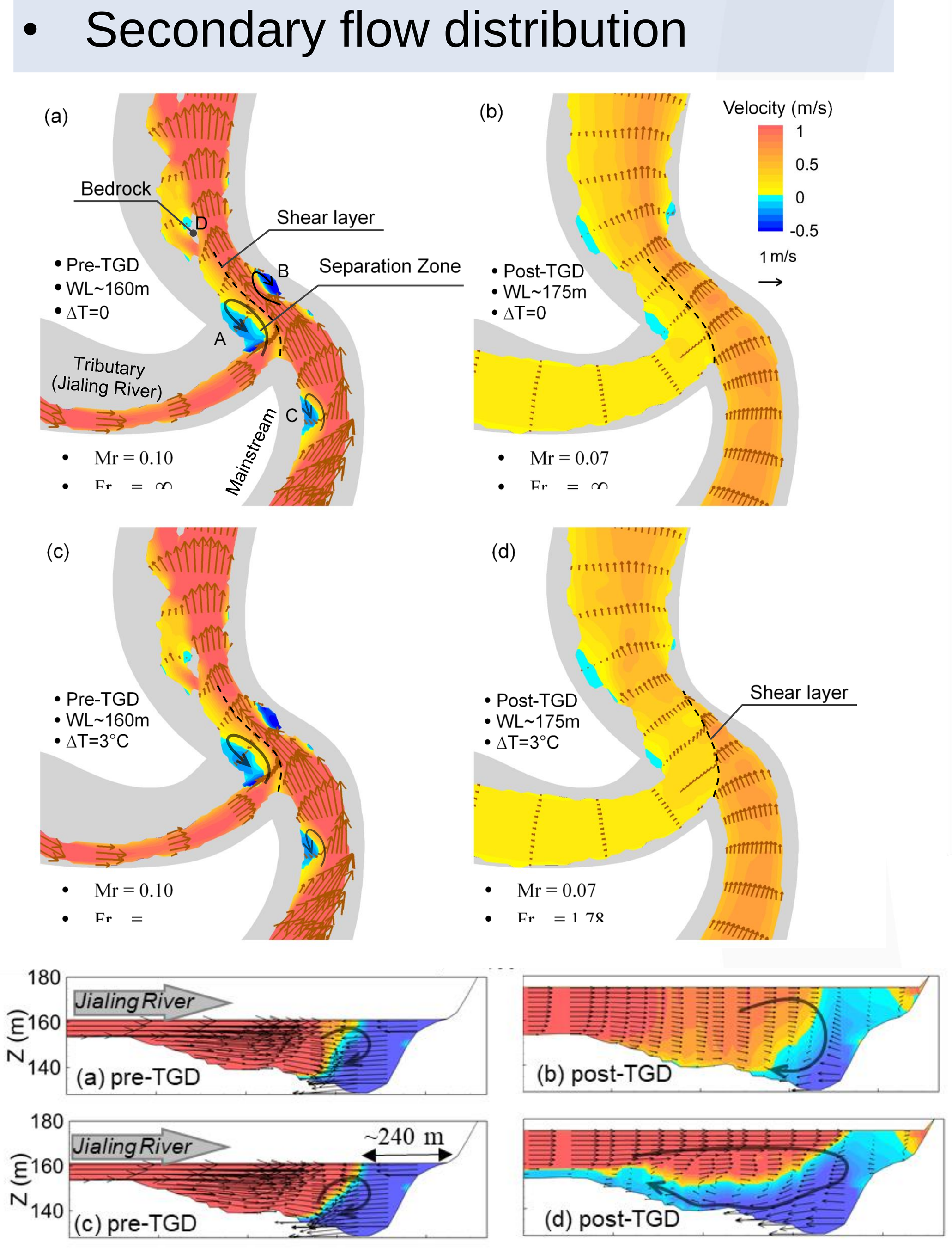


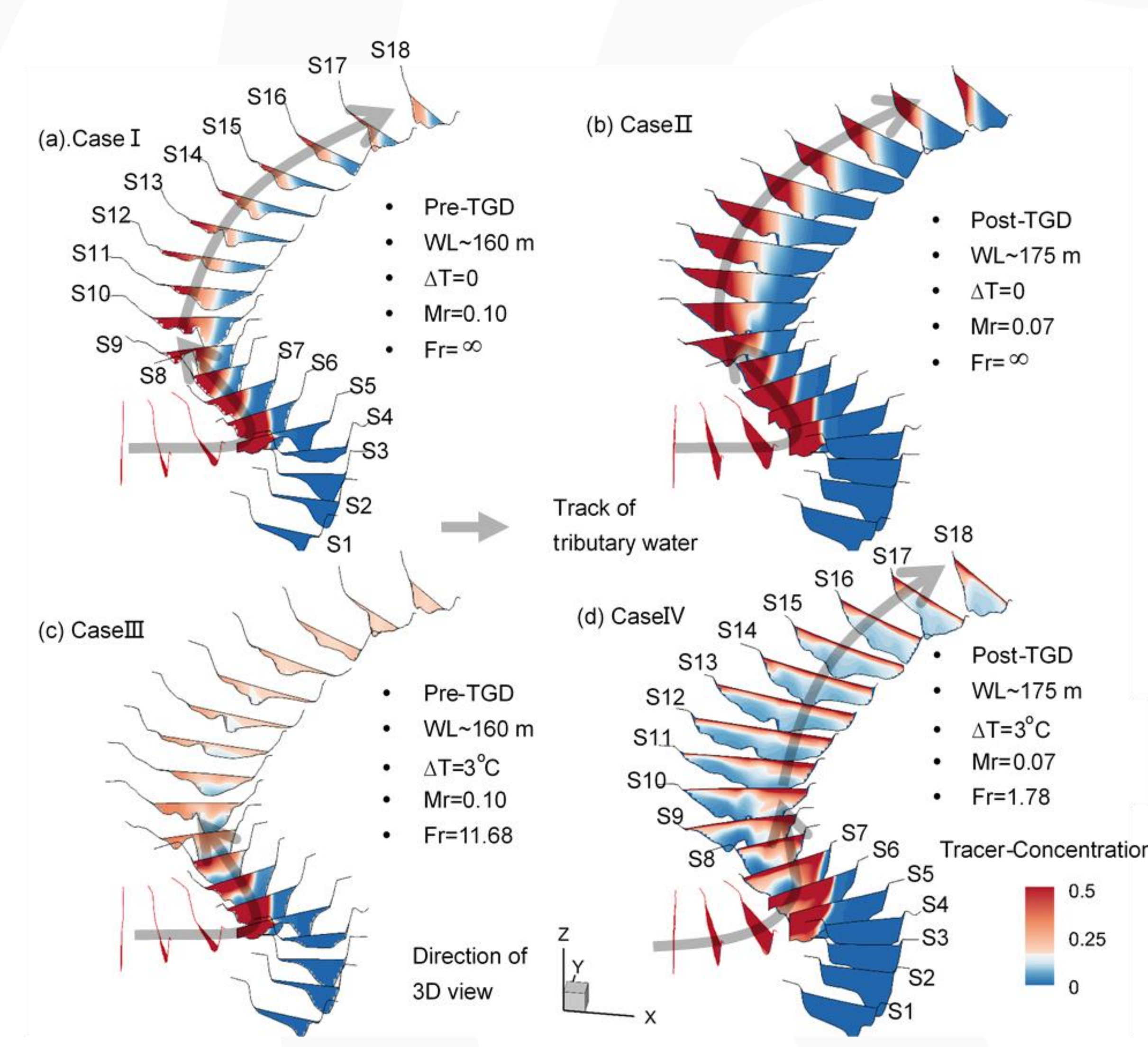
Density difference: (a) Annual density difference. (b) Regional temperature distribution.

Hydro-Thermodynamic processes at the confluence

Hydrodynamic Processes:

- Horizontal surface flow distribution
- Secondary flow distribution





Mixing processes at the confluence:
The tracer concentration in the confluence area during pre-TGD (a, c) and post-TGD (b, d) periods; In panels (a) and (b), water temperatures from the mainstream and tributary are same, while in panel (c) and (d), there is a tributary temperature excess of 3°C

Key Points

- Reservoir regulation has altered the flow pattern of a large confluence significantly in both the horizontal plane and cross-sections.
- The tributary-mainstream temperature difference changes hydro-thermodynamic processes, especially when combined with dam operation.