EGU General Assembly 2026 | NH1.1: Compound extremes in hydro-meteorology

Extreme Saltwater Intrusion in the Yangtze Estuary under Compound Drought, Wind Forcing, and Sea-Level Rise

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Motivation

- Coastal megacities face increasing **saltwater intrusion (SWI)** risk under climate change — threatening freshwater security for hundreds of millions
- **Shanghai**: >24 million people, **>80%** freshwater from the Yangtze Estuary — highly vulnerable to SWI
- **2022 megadrought**: Record-breaking event — Qingcaosha Reservoir experienced **98 consecutive days** of unfit water intake
- **Key question**: How do compound drought, wind forcing, and future SLR interactively affect SWI intensity?

THE COMPOUND THREAT

Drought

Reduced river discharge weakens freshwater flushing

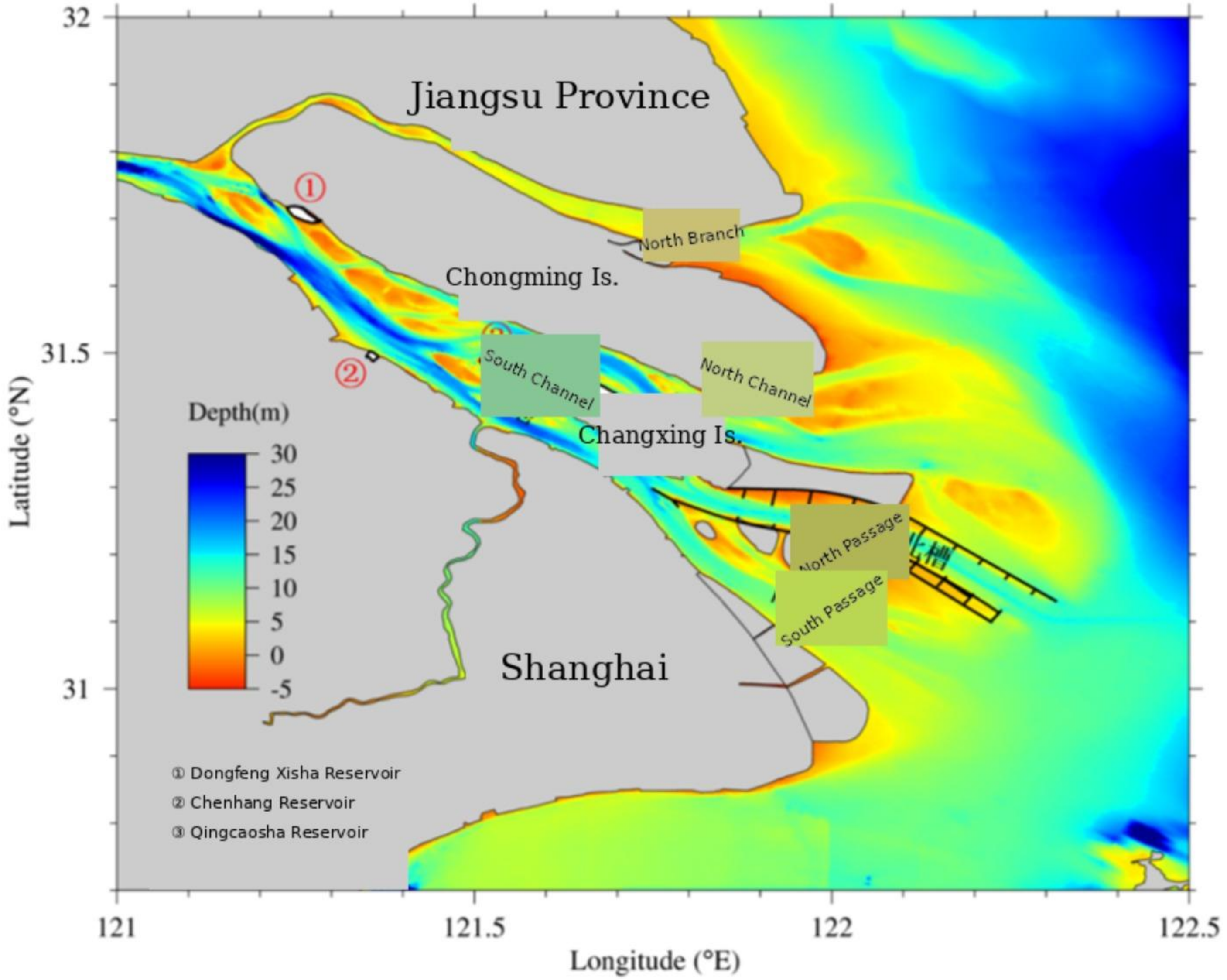
Wind

Northerly wind drives landward Ekman transport

SLR

Sea-level rise amplifies all intrusion pathways

Study Area: The Yangtze Estuary



Multi-order bifurcation

North/South Branch -> North/South Channel -> North/South Passage

Three reservoirs

- Qingcaosha (largest)
- Chenhang
- Dongfengxisha

Hydrology

Mean tidal range: 2.5-3.0 m

Dry-season discharge: ~10,000 m^3/s

Safety threshold

0.45 psu (drinking water standard)

Model: UFDECOM-i (Ma, 2022)

3D unstructured-grid model

Based on ECOM-si (Blumberg & Mellor, 1987)

Key improvements

- IGNES implicit nesting
- NBFCI flux-conservative interpolation

Resolution

- ~100 m near bifurcation points
- 45,964 grid cells
- 10 σ-layers

Validation metrics (SS)

Water level: **>0.96** | Current: **>0.81** | Salinity: **>0.71**

EXPERIMENTAL DESIGN

2022 Extreme Event (real forcing)

↓

4 SLR scenarios (0 – 1.17 m)

↓

4 Discharge levels (8000–15000)

↓

2 Wind scenarios (mean / 10 m/s N)

Total: **28** numerical experiments

(4 + 16 + 8)

The 2022 Extreme Event: What Happened?

MEGADROUGHT

- Basin-wide drought across the Yangtze River basin
- River discharge dropped to historic lows
- Freshwater flushing severely weakened

WIND

- Persistent northerly winds during summer
- Max wind speed: **24.9 m/s**
- Landward Ekman transport intensified

IMPACT

- Qingcaosha: **98 days** unfit for intake
- Chenhang: +51.6% unfit duration
- City-wide water supply emergency

Compound mechanism: The coincidence of drought (reduced discharge) and strong northerly wind (enhanced landward transport) created a "perfect storm" for saltwater intrusion — far exceeding the impact of either driver alone.

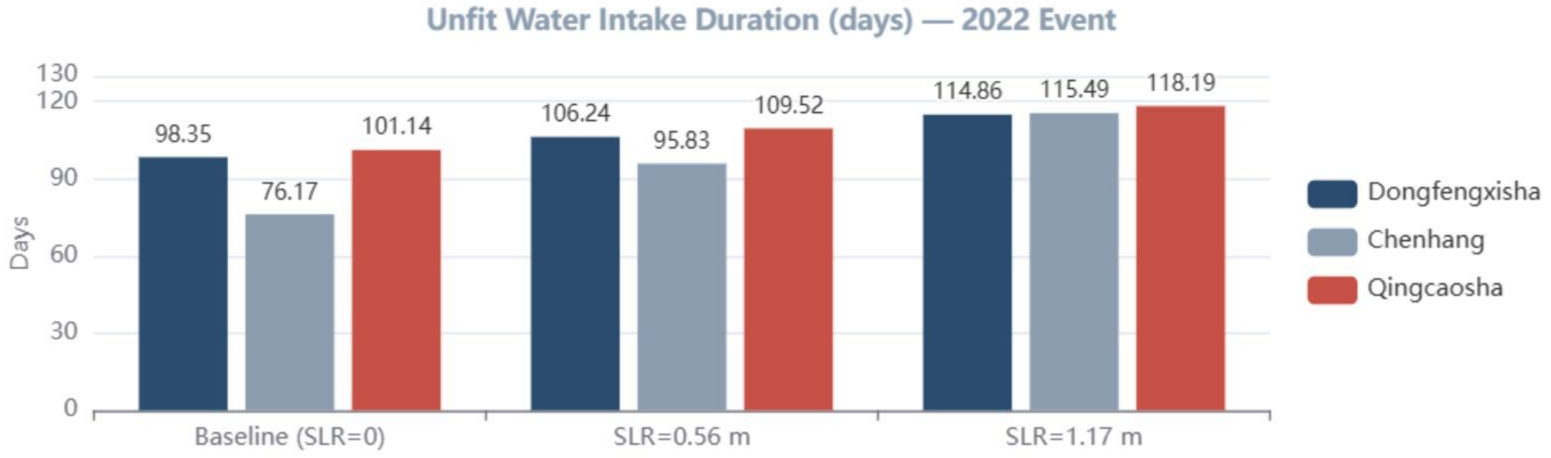
This event highlighted the urgent need to understand **compound extremes** in estuarine systems under future climate change scenarios.

Results — 2022 Extreme Saltwater Intrusion

98 days

Consecutive unfit-intake days

at Qingcaosha Reservoir (2022)



KEY MECHANISMS IDENTIFIED

1. Reduced freshwater flushing

Low discharge weakened the seaward pressure that normally keeps saltwater at bay

2. Anomalous horizontal circulation

"North Channel inflow, South Channel outflow" driven by northerly wind

3. SLR amplification: At SLR = 1.17 m, Chenhang Reservoir unfit duration increased from 76.17 d to **115.49 d (+51.6%)**

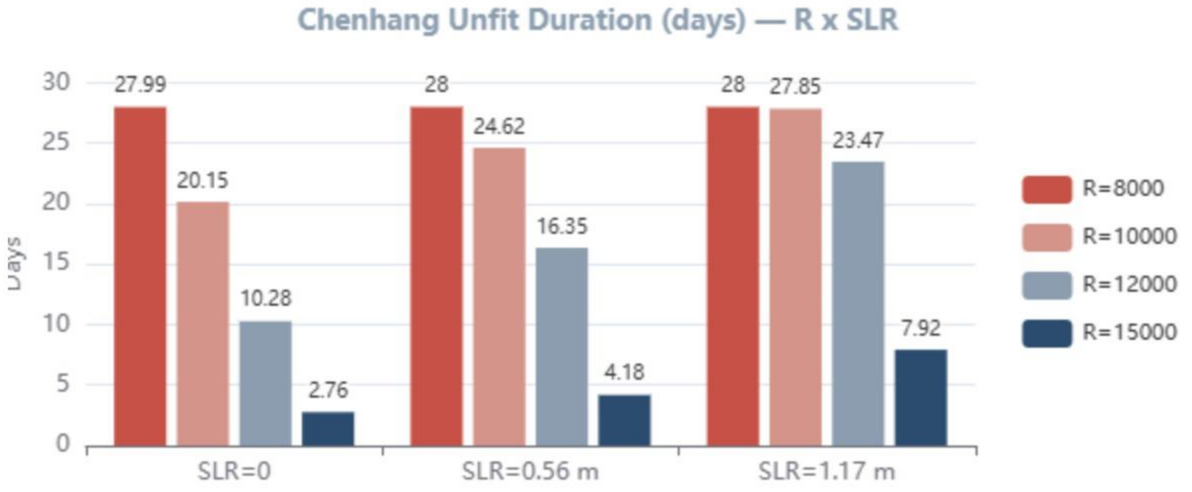
Results — SLR x Reduced Discharge Compound Effect

16-group matrix: 4 SLR x 4 constant discharge

Finding 1: River discharge is the **dominant factor**; SLR acts as an amplifier

Finding 2: At R = 15000 m^3/s, all reservoirs remain safe even under maximum SLR

Finding 3: At R = 8000 m^3/s, all three reservoirs approach full-month unfit intake at SLR >= 0.80 m



CRITICAL RISK ZONE

When **R <= 12,000 m^3/s** meets **SLR >= 0.80 m**, system vulnerability rises sharply — all three reservoirs face near-complete loss of intake capacity.

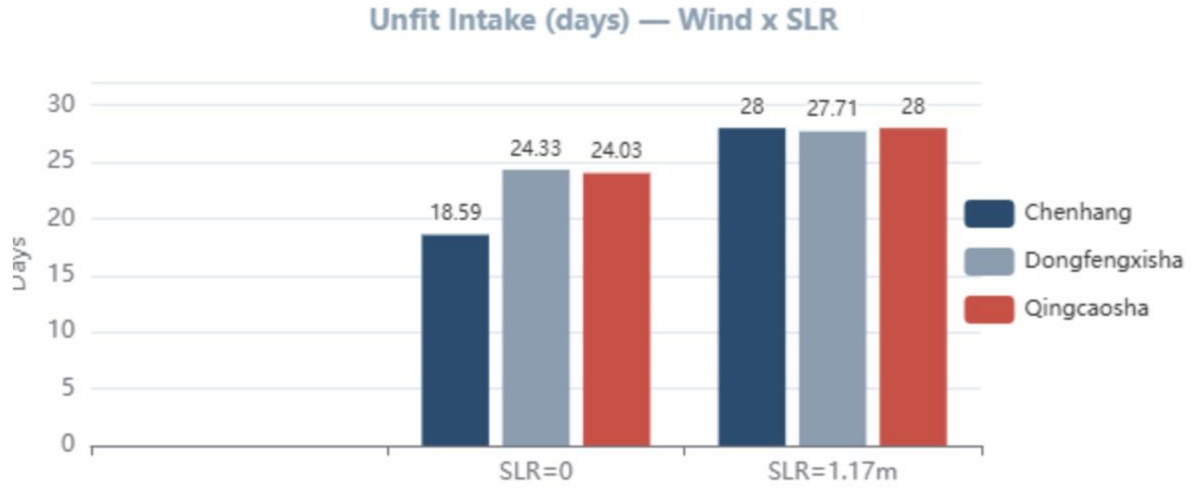
At **R = 10,000 m^3/s + SLR = 1.17 m**: Chenhang and Qingcaosha both approach **28 days** of unfit intake — the entire month becomes unusable.

Results — SLR x Strong Northerly Wind Compound Effect

8-group matrix: 4 SLR x 2 wind scenarios

- W1: Monthly mean wind (control)
- W2: 10 m/s persistent north wind

Core finding:
SLR determines the "salinity baseline"
Wind determines the "salinity peak"
Their superposition creates compound high-risk



COMPOUND EFFECT INSIGHT

At **SLR = 1.17 m + strong northerly wind**: All three reservoirs approach **28 days** of unfit intake — nearly the entire month is lost.

This means future extreme wind events, when superimposed on higher baseline sea levels, will produce **saltwater intrusion severity never observed in the historical record** — a genuine compound extreme.

Key Takeaways

1. **The 2022 megadrought caused record-breaking SWI**
   Qingcaosha Reservoir: **98 consecutive unfit-intake days** — a new historical record for the Yangtze Estuary

2. **Compound drought + wind created anomalous circulation**
   "North-in-South-out" horizontal circulation intensified salt transport into the estuary

3. **Future SLR (1.17 m) non-linearly amplifies SWI**
   Chenhang Reservoir unfit-intake duration increased by **+51.6%** compared to present conditions

4. **Critical risk threshold identified**
   When $R \leqslant 12{,}000\ m^3/s$ combines with $SLR \geqslant 0.80$ m, **all three reservoirs face system-wide failure**

This work provides quantitative evidence for climate-resilient water resource management in the Yangtze Estuary and other vulnerable estuarine systems worldwide.

Thank You

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Open for discussion and collaboration