



# Weather Hazards Dynamically Reshape Navigability in China's Inland Waterways



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Inland waterways are often underappreciated, yet they are vital for connecting industries to seaports and sustaining global trade.



- Connects domestic industries to seaports and global markets
- Handles bulk cargo with low cost, high energy efficiency, and large capacity
- Supports regional economies and global supply chains
- A key component of sustainable and resilient transport systems

## A Global Perspective: Three Major Representative Inland Waterway Systems

<p><b>Rhine River</b> Europe</p> <p>Annual Cargo Volume <b>310 million tons*</b></p> <p>Main Cargoes Minerals, Coal, Chemical products, Petroleum products, Metals, Containers, Construction materials, Agricultural products, etc.</p> <p><small>* Source: Central Commission for the Navigation of the Rhine (CCNR, 2025)</small></p>	<p><b>Yangtze River</b> China</p> <p>Annual Cargo Volume <b>4.2 billion tons*</b></p> <p>Main Cargoes Coal, Ore, Construction materials, Steel, Containers, Petroleum products, Grain, Chemical products, etc.</p> <p><small>* Source: Ministry of Transport of China (2025)</small></p>	<p><b>Mississippi River</b> United States</p> <p>Annual Cargo Volume <b>500 million tons*</b></p> <p>Main Cargoes Agricultural products (corn, soybeans, etc.), Coal, Petroleum products, Chemicals, Building materials, Fertilizers, etc.</p> <p><small>* Source: USACE (2025) – Navigation Data Center</small></p>
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### Our Research Focus

**The Yangtze River Basin: The World's Busiest Inland Waterway System**

- The Yangtze River has ranked first in the world in annual cargo volume for many consecutive years.
- It connects inland economic hubs with seaports, supporting national development and global trade.

### Weather Hazards

Low Visibility Fog, haze reducing visibility	Strong Winds Crosswinds, gusts impacting navigation	Heavy Rainfall Flooding, rapid water level rise	Snowfall Snow and ice affecting channel conditions

### Quantitative Impact Assessment

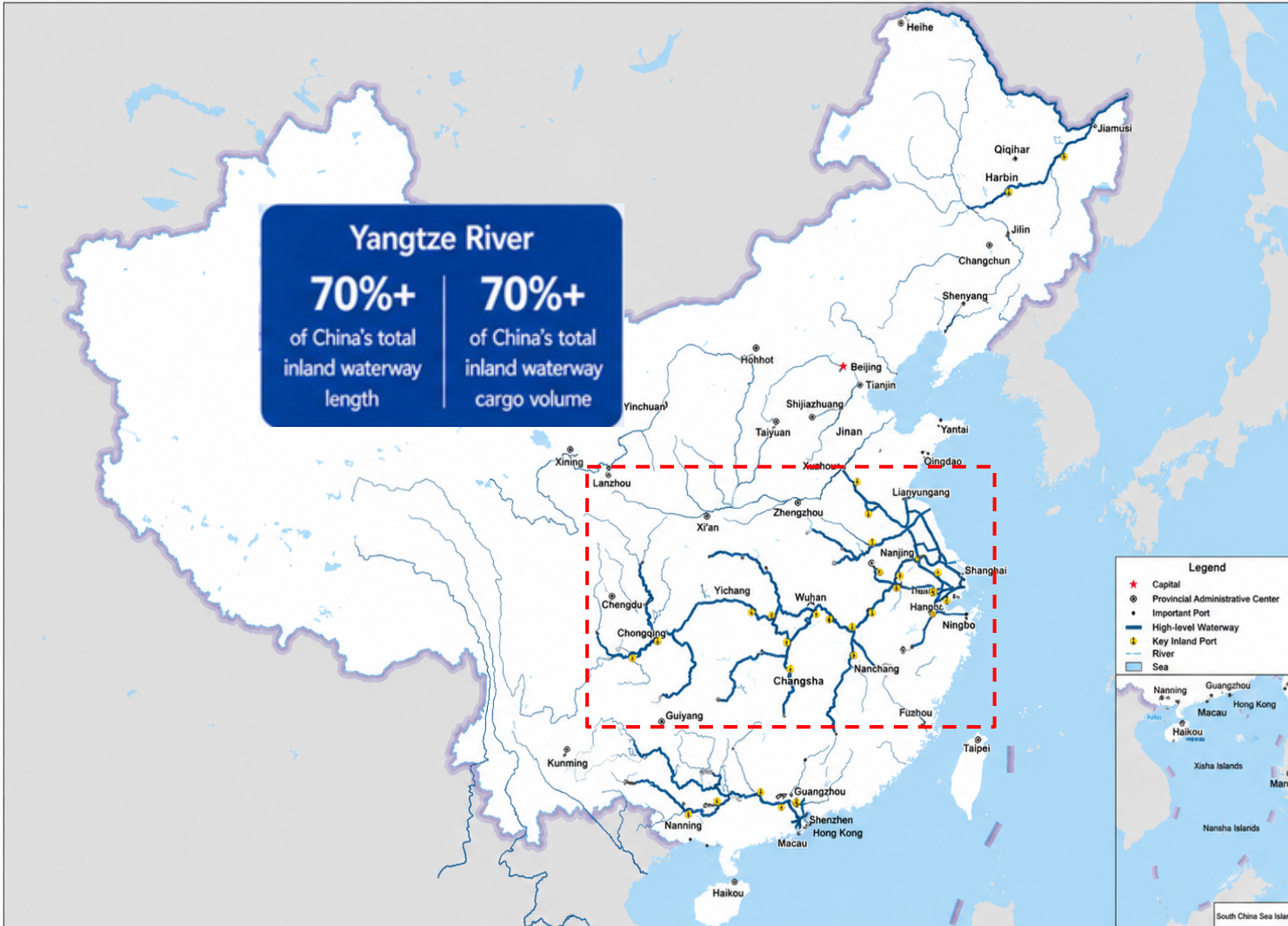
Quantifying the impacts of weather hazards on navigation conditions, transport capacity, and key economic indicators to support risk management and build the resilience of inland

Our aim is to **quantitatively assess** how weather hazards **influence** navigation in China's inland waterways, providing scientific evidence for **risk management** and **enhancing the resilience** of inland navigation.

# Study Area Overview



The Yangtze River is the backbone of China's inland waterway system



## China's Inland Waterway Network

A nationwide network of high-grade waterways spanning 16,000+ km



### 1 Yangtze River Waterway

8,900 km

- 2025 cargo volume: 4.2 billion tons



### 2 Pearl River Waterway

2,620 km

- 2025 cargo volume: 1.6 billion tons



### 3 Heilong River Waterway

2,380 km

- 2025 cargo volume: < 0.1 billion tons



The Yangtze River contributes more than **70%** of China's inland waterway length and cargo volume.

# Study Methods



## Inland Waterway Network in the Yangtze River Basin



## Types of Weather Hazards Affecting Navigability



Low  
Visibility



Strong  
Winds



Short-duration  
Heavy Rainfall



Snowfall



High  
Temperature

General Impacts on Navigability

Hazardous Materials Only



## Relevant Industry Standards

• Classification of Meteorological Conditions for Ship Navigation	(2016)
• Regulations for Prohibiting Ship Navigation under Adverse Weather Conditions on the Yangtze Mainline	(2016)
• Standard for Ship Navigation on the Yangtze Mainline	(2020)
• Guidelines for Meteorological Conditions Classification for Waterborne Transportation	(2020)
• Classification and Assessment Standards for Waterborne Meteorological Disaster Risk Warning	(2021)
• Classification for Inner Waterway Navigation Meteorological Risk Warning	(2023)
• Classification for Meteorological Risk Warning of Ship Navigation Safety in the Hubei Section of the Yangtze Mainline	(2024)
• Forecast and Warning Service Products for Inner Waterway Navigation Meteorology	(2025)



These standards provide the **regulatory foundation** and **technical guidance** for our evaluation framework.

# Study Methods



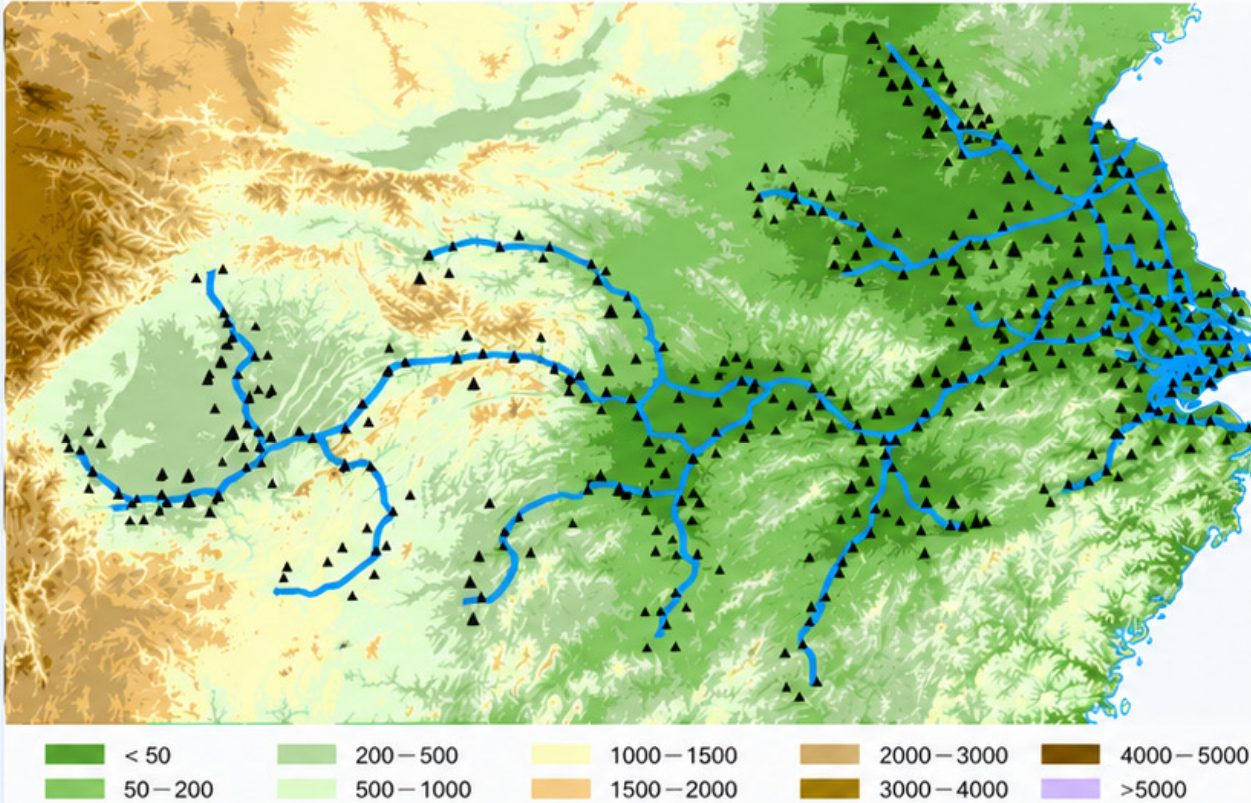
## Classification Thresholds of Meteorological Conditions for the Yangtze Waterway



Level	Classification Criteria	
 <b>Navigable</b> (Normal Operation)	<b>All of the following conditions must be met:</b> <ul style="list-style-type: none"> <li>Effective visibility <math>\geq 2.0</math> km</li> <li>Maximum wind speed <math>&lt; 8.0</math> m/s</li> <li>6-hour precipitation <math>&lt; 50</math> mm</li> <li>1-hour precipitation <math>&lt; 10</math> mm</li> <li>12-hour snowfall <math>&lt; 6</math> mm</li> </ul>	<b>Normal Conditions</b> Safe navigation under normal operation.
 <b>Cautionary</b> (Low Risk)	<b>Any one of the following conditions is met:</b> <ul style="list-style-type: none"> <li>Effective visibility <math>\geq 1.0</math> km, and <math>&lt; 2.0</math> km</li> <li>Maximum wind speed <math>\geq 8.0</math> m/s, and <math>&lt; 10.8</math> m/s</li> <li>6-hour precipitation <math>\geq 50</math> mm</li> <li>1-hour precipitation <math>\geq 10</math> mm, and <math>&lt; 20</math> mm</li> <li>12-hour snowfall <math>\geq 6</math> mm</li> </ul>	<b>Low Risk</b> ..... Navigation with caution. Increase distance between vessels.
 <b>Restricted</b> (Medium Risk)	<b>Any one of the following conditions is met:</b> <ul style="list-style-type: none"> <li>Effective visibility <math>\geq 0.5</math> km, and <math>&lt; 1.0</math> km</li> <li>Maximum wind speed <math>\geq 10.8</math> m/s, and <math>&lt; 13.9</math> m/s</li> <li>3-hour precipitation <math>\geq 50</math> mm, and <math>&lt; 100</math> mm</li> <li>1-hour precipitation <math>\geq 20</math> mm, and <math>&lt; 50</math> mm</li> <li>6-hour snowfall <math>\geq 10</math> mm, and <math>&lt; 15</math> mm</li> </ul>	<b>Medium Risk</b> ..... One-way navigation only.
 <b>Prohibited</b> (High Risk)	<b>Any one of the following conditions is met:</b> <ul style="list-style-type: none"> <li>Effective visibility <math>&lt; 0.5</math> km</li> <li>Maximum wind speed <math>\geq 13.9</math> m/s</li> <li>3-hour precipitation <math>\geq 100</math> mm</li> <li>1-hour precipitation <math>\geq 50</math> mm</li> <li>6-hour snowfall <math>\geq 15</math> mm</li> </ul>	<b>High Risk</b> ..... Navigation strictly prohibited.

Classification is determined by the **most severe level** of any single meteorological factor being reached.

## Meteorological Station Distribution along the Yangtze River and Grand Canal



**236 meteorological stations**

located within 20 km of the Yangtze River and Grand Canal



### Historical Observations Collected

- Horizontal visibility (hourly)
- Precipitation / Snowfall (hourly)
- Maximum 10-minute average wind speed (10-min)



Period:  
1980-01-01 to  
2024-12-31



### Data Quality Control and Gap Filling

- If the missing rate of any key meteorological element (precipitation, wind speed, visibility, etc.) exceeds 10% in a given month at a station, the data for that month is deemed invalid.
- For valid months, missing data are filled using the nearest-neighbor interpolation method to ensure data continuity.



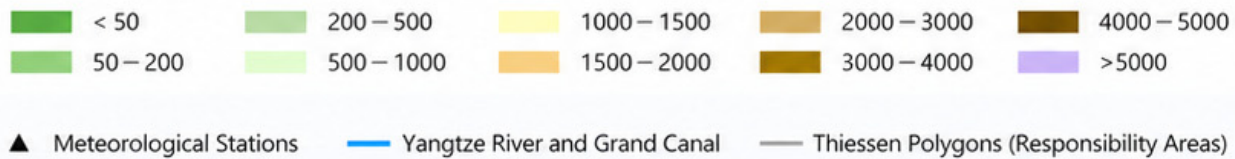
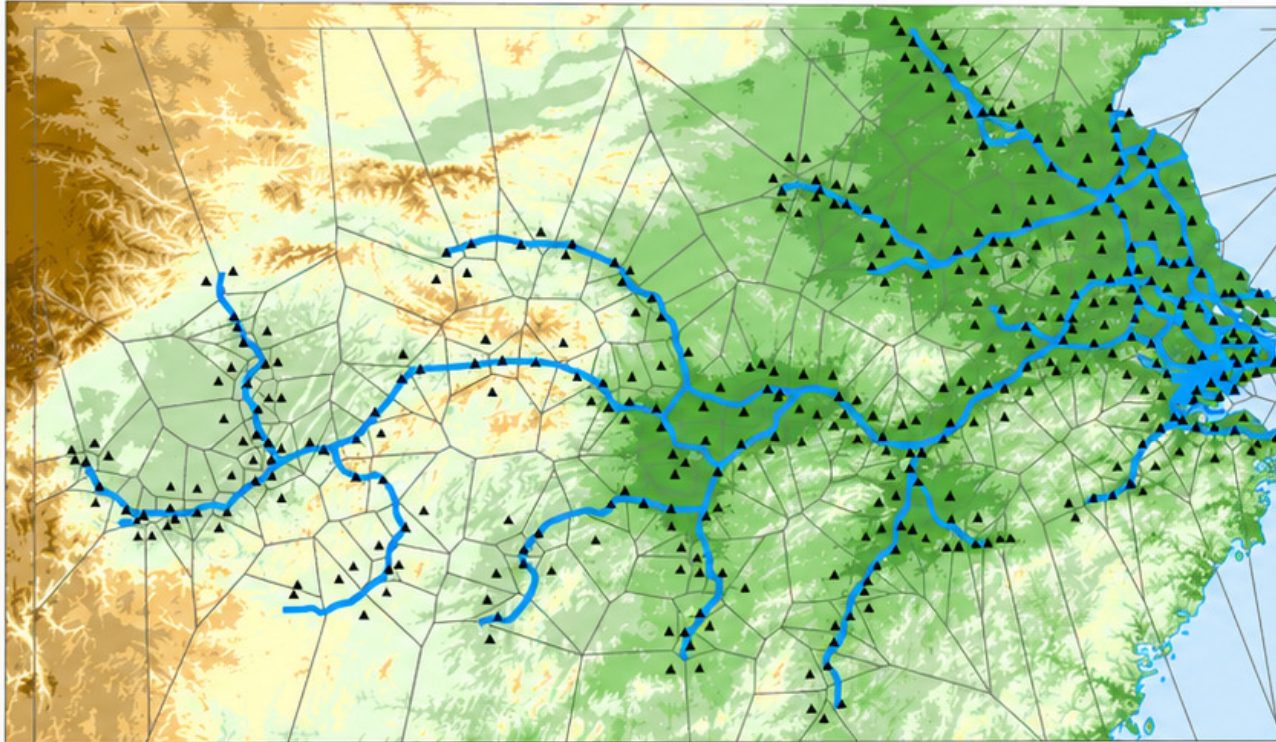
### Visibility Data Adjustment

- Considering the transition from manual to automatic observations around 2014, and that manual observations tend to overestimate visibility, this study applies the empirical formula recommended by the WMO to adjust visibility data.
- Daily 08:00 visibility observations are used for navigability assessment, as low-visibility weather on the Yangtze River is primarily caused by fog, which occurs most frequently and is most representative at 08:00, better reflecting the actual impact on navigation.



Our objective is to build a **High-quality, continuous, and homogenized meteorological dataset** to support the assessment of navigability conditions on the Yangtze Waterway.

## Thiessen (Voronoi) Polygon Model for Responsibility Segmentation



### Method

- Thiessen (Voronoi) polygons are constructed based on **236** meteorological stations to accurately delineate the responsibility waterway segments for each station.



### Coverage

- On average, each station covers approximately **40 km** of the waterway.



### Current Limitation

- The coverage density cannot fully meet the ideal requirement for navigability assessment.
- This reflects the current capability of China's meteorological observation network.



### Application

- We utilize the historical observations from these stations to conduct a long-term analysis of navigability conditions on the Yangtze Waterway.



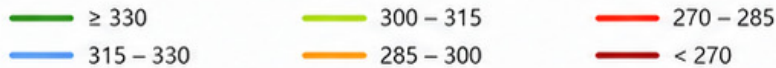
This approach enables a **scientifically based** and **practical** mapping of meteorological responsibility along the waterway network.

# Results 1

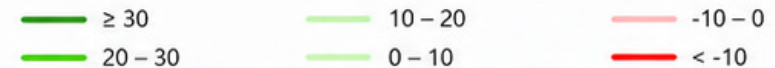
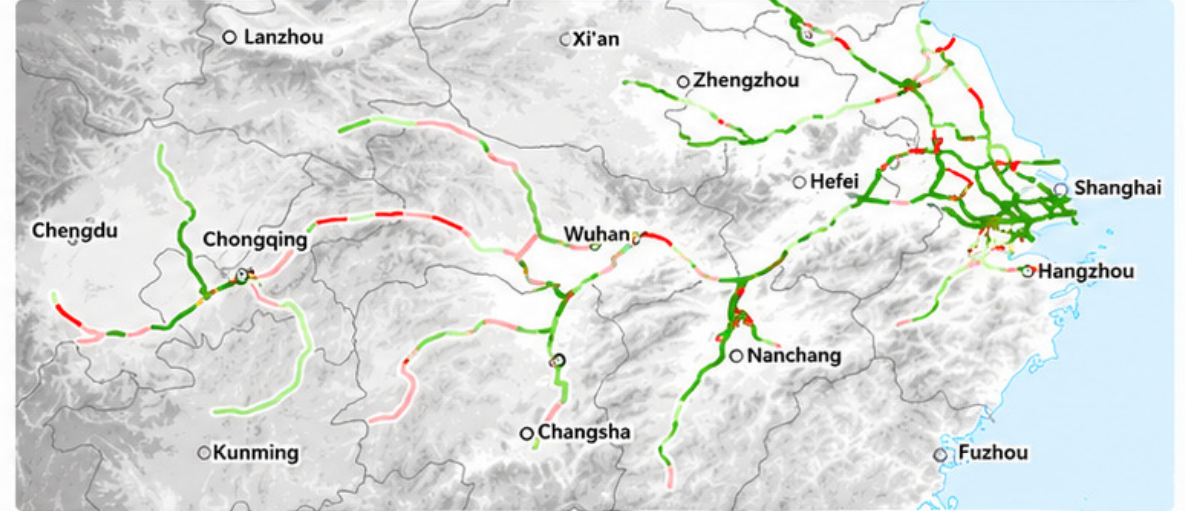


## Spatial Distribution and Change of Navigable Days on the Yangtze Waterway

### Spatial Distribution of Navigable Days (2000–2024)



### Change in Navigable Days (2000–2024 vs 1980–1999)



### Average navigable days: 301 days

- **Upstream: fewer**  
Lowest in Shuifu–Chongqing (255 days)  
Chongqing–Yichang: 291 days
- **Midstream: more**  
Highest in Yichang–Wuhan (317 days)
- **Downstream: moderate**  
Wuhan–Nanjing: 304 days  
Nanjing–Estuary: 303 days  
Yangtze Delta: 299 days

Overall pattern: fewer days in the upstream, more in the midstream, and moderate in the downstream.



### Average change: +23 days

Over 80% of the waterway shows an increase in navigable days.

- **Upstream: improvement**  
Shuifu–Chongqing: +37 days  
Chongqing–Yichang: +12 days
- **Midstream: continued improvement**  
Yichang–Wuhan: +20 days
- **Downstream and Yangtze Delta: improved**  
Wuhan–Nanjing: +17 days  
Nanjing–Estuary: +34 days  
Yangtze Delta: +21 days

Overall, navigable days have increased significantly across the entire waterway, with the most notable improvements in key upstream and downstream sections.

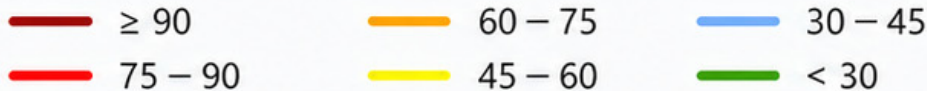
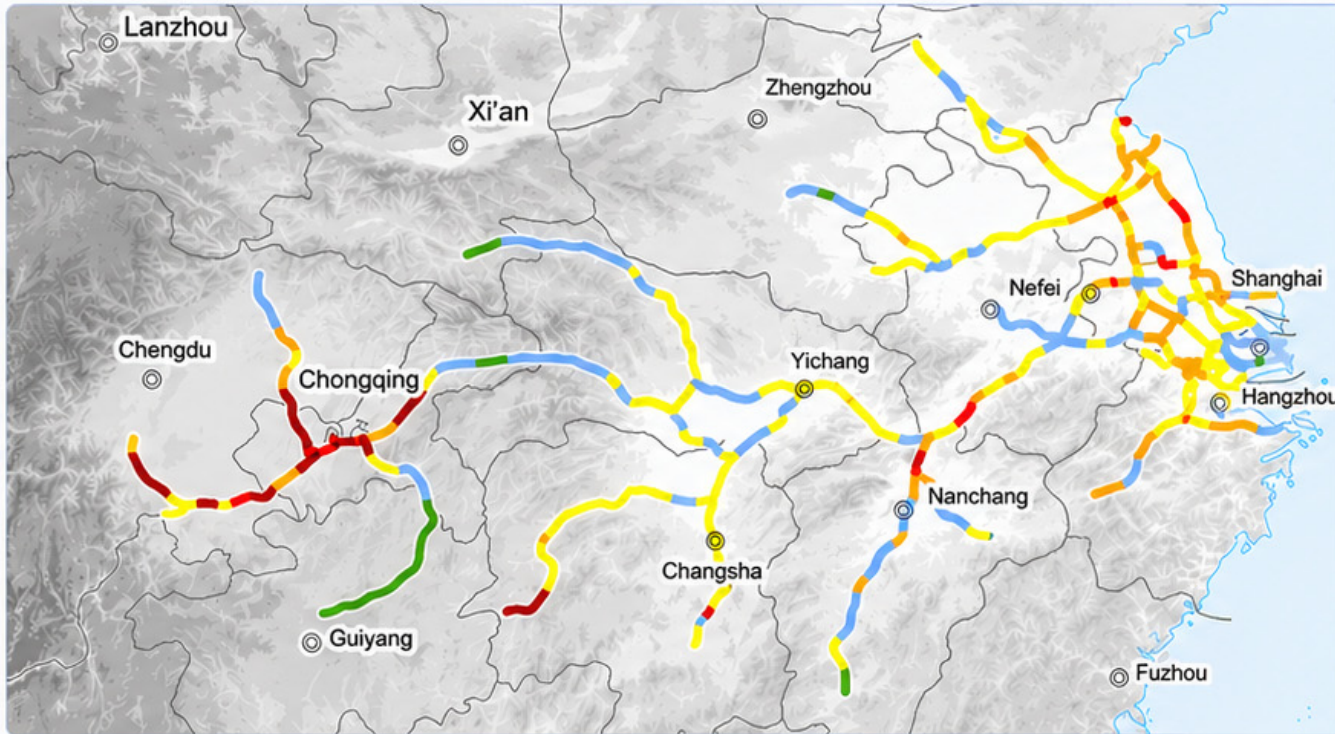


The Yangtze Waterway shows a clear **increase in navigable days** over the past four decades, indicating a **continuous improvement** in navigability conditions and promising gains in navigation efficiency and safety.

# Results 2



## Spatial Distribution of Unfavorable Navigable Days (Cautionary, Restricted, and Prohibited Conditions) 2000–2024



### Overall Indicator

Average unfavorable navigable days:  
**65 days**



### Upstream: Most Frequent

- Shuifu–Chongqing: 111 days (highest)
- Chongqing–Yichang: 74 days

*Frequent low-visibility weather (e.g., morning fog) in complex mountainous terrain leads to more unfavorable conditions.*



### Midstream: Best Conditions

- Yichang–Wuhan: 48 days (lowest)

*Relatively flat terrain and fewer hazardous weather events result in the best navigable environment.*



### Downstream: Moderate

- Wuhan–Nanjing: 61 days
- Nanjing–Estuary: 62 days

*Although lower than upstream, these busy shipping sections still require close attention for navigation efficiency and safety.*



Unfavorable navigable days show a clear **inverse pattern** to navigable days: frequent in the upstream, least in the midstream, and moderate in the downstream.

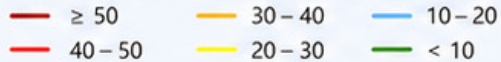
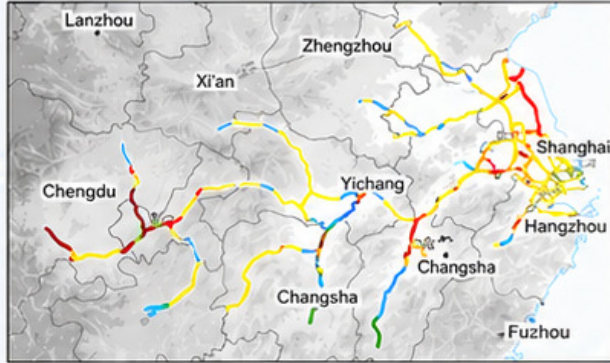
# Results 3



## Contribution and Spatial Distribution of Different Hazard Types to Unfavorable Navigable Days (2000–2024)

44 days

### Low Visibility



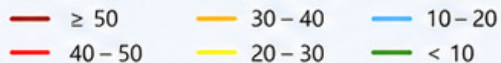
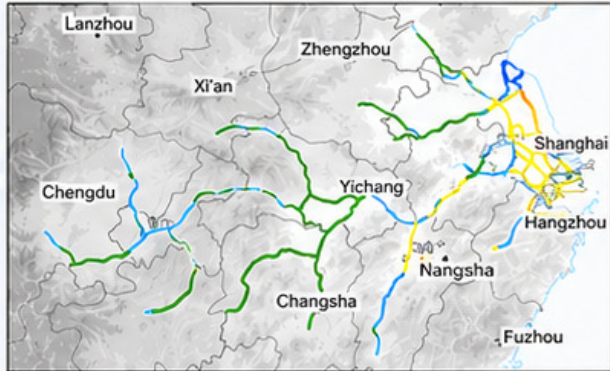
### Strong Wind



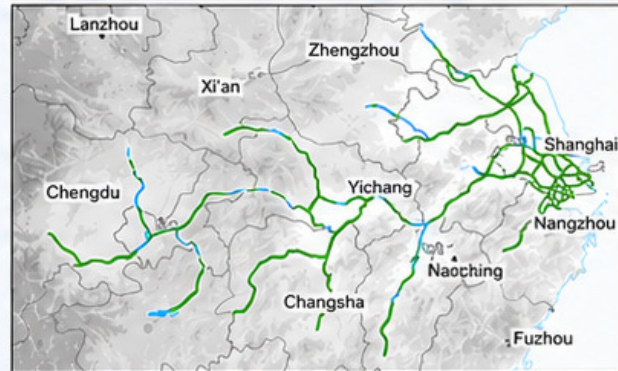
14 days

11 days

### Heavy Rain



### Snowfall



0.1 days



### Overall

From 2000–2024, the Yangtze Waterway experiences an average of **54 unfavorable navigable days** per year.



### Dominant Hazard: Low Visibility

Low-visibility weather contributes the most (**44 days**), especially in the upstream reaches and the Yangtze River Delta, while the midstream has the fewest (~30 days).



### Strong Wind

Mainly affects the midstream and downstream reaches (**14 days**). Compared with 1980–1999, strong-wind days **decreased by 17 days (>50% reduction)**, showing the most significant improvement.



### Heavy Rain

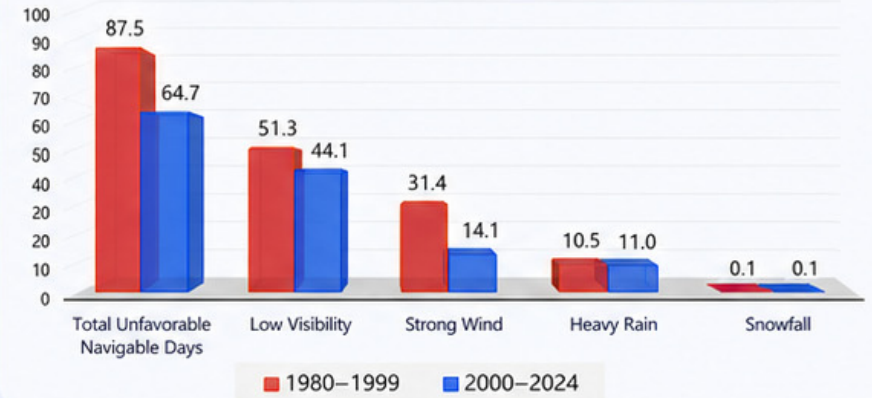
Shows a decreasing pattern from southeast to inland (**11 days**). The change compared with 1980–1999 is minor.



### Snowfall

Impact is negligible (**<0.1 days**).

### Historical Changes in Unfavorable Navigable Days (Days/year)



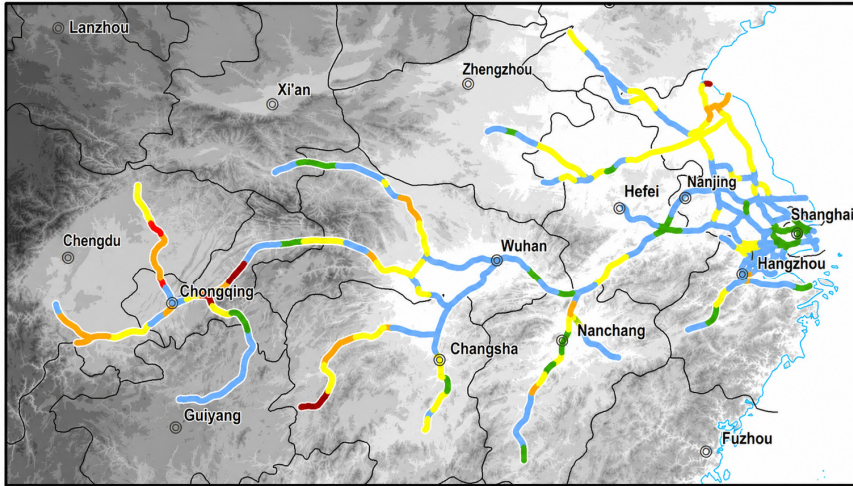
Low visibility is the **dominant contributor** to unfavorable navigable days, followed by **strong wind** and **heavy rain**, while snowfall has negligible impact.

# Results 4



## Spatial Distribution and Historical Changes of Prohibited Navigable Days (2000–2024)

### Spatial Distribution of Prohibited Navigable Days (2000–2024)



Overall average:  
**10 days**

- Upstream reaches are generally 10–20 days, some even >20 days.
- Midstream and downstream reaches are generally 5–10 days.

**Upstream:** mainly low visibility  
**Midstream & downstream:** mainly strong wind, also low visibility

Heavy rain is frequent in the midstream and downstream, but rarely reaches prohibited levels.

### Historical Changes of Prohibited Navigable Days

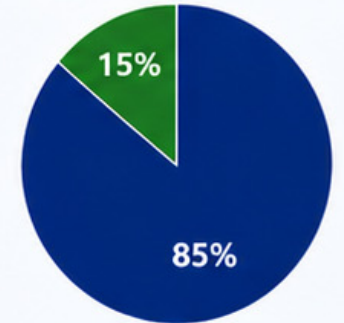
Prohibited navigable days decreased from 14 to 10 days

	1980–1999 (days)	2000–2024 (days)	Change (days)
Low Visibility (main driver)	9.5	7.1	-2.4
Strong Wind	4.1	2.4	-1.7
Heavy Rain	0.2	0.3	+0.1
Snowfall	0.0	0.0	0.0



Overall improvement is evident.  
Low visibility remains the key concern:  
7 out of 10 prohibited days are caused by low visibility.

### Causes of Low Visibility (2000–2024)

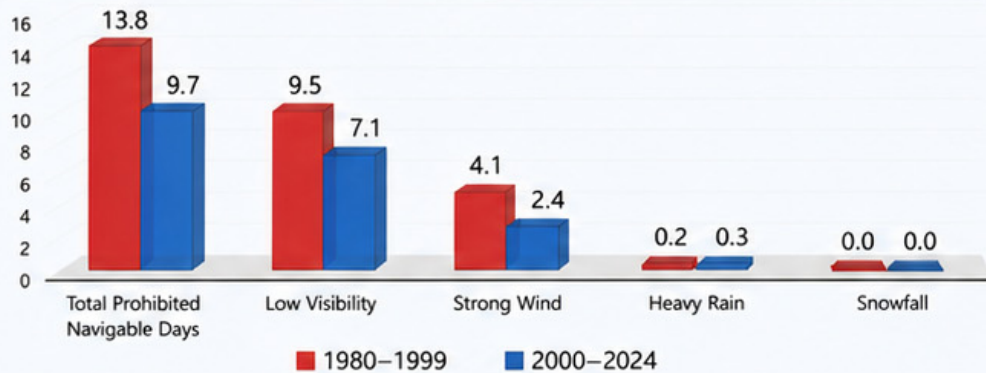


■ Fog (85%) ■ Haze (15%)



Low visibility is dominated by fog and should be the primary focus of prevention and control.

### Historical Changes in Prohibited Navigable Days (days/year)



### Mitigation and Improvement Potential

#### Non-engineering measures to address low visibility:

- ✓ Enhance monitoring and early warning
- ✓ Install navigation radar
- ✓ Adjust navigation schedules to avoid peak fog periods (e.g., morning fog, clearing by noon)
- ✓ High-frequency season: January, November, December (winter)

#### Significant potential through navigation radar technology

Visibility Threshold for Navigability	Navigable Days (days/year)	Unfavorable Navigable Days (days/year)	Reduction in Unfavorable Navigable Days
Current (2000 m)	301	65	–
1000 m	326	39	-38% ↓
500 m	336	29	-55% ↓



Lowering the visibility threshold can significantly increase navigable days and reduce unfavorable days, demonstrating great potential.



Prohibited navigable days average 10 days per year along the Yangtze Waterway during 2000–2024.

**Low visibility** is the key driver (7 days), concentrated in winter (Jan, Nov, Dec), with **fog** accounting for 85% of low-visibility events.

Non-engineering measures and radar technology offer **substantial potential** to mitigate its impact.

# Key Takeaways



## Navigable Days (2000–2024)

**301** days

The Yangtze Waterway experiences an average of **301** navigable days per year during 2000–2024.



## Improvement Compared to the Historical Period

**77%** of the waterway shows an increase in navigable days.

The average increase is **23** days.



## Unfavorable Navigable Days by Hazard Type (2000–2024)

**44**



Low Visibility

**14**



Strong Wind

**11**



Heavy Rain

**< 1**



Snowfall

Among **65** unfavorable navigable days, low visibility accounts for **44** days (68%).



## Low Visibility Breakdown (2000–2024)

**38** days

Fog

**9** days

Haze

Among the **44** low-visibility days, **38** days are due to fog (86%) and **9** days to haze (14%).



## Prohibited Navigable Days (2000–2024)

**10** days Average prohibited navigable days per year.

- 7 out of 10 days are caused by low visibility.
- Most frequent in January, November, and December.



## Low Visibility is the Dominant Driver

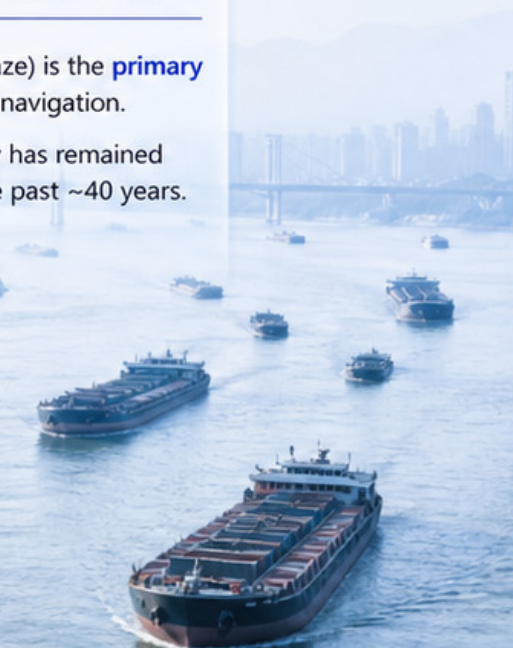
- Low visibility (fog and haze) is the **primary** weather factor affecting navigation.
- Its occurrence frequency has remained relatively **stable** over the past ~40 years.



## Significant Potential of Navigation Radar Technology

Reducing the navigable visibility threshold can substantially increase navigable days and reduce unfavorable days.

Visibility Threshold	Navigable Days (days/year)	Unfavorable Navigable Days (days/year)	Reduction in Unfavorable Navigable Days
Current (2000 m)	311	65	–
1000 m	<b>326</b>	<b>39</b>	<b>–38%</b> ↓
500 m	<b>335</b>	<b>29</b>	<b>–56%</b> ↓





# Thank You!

## for Your Attention



**I appreciate your time and interest.**

I look forward to your questions and to future collaborations!



**Interested in Collaborating on Research in China?**

I welcome discussions and collaborations on weather-related research in:



Waterway  
Navigation



High-Speed  
Rail



Drone Delivery  
(UAV)



Livable  
Cities

Feel free to reach out if you are interested in joint research or data sharing.

EGU General Assembly 2026

Natural Hazards (NH)

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