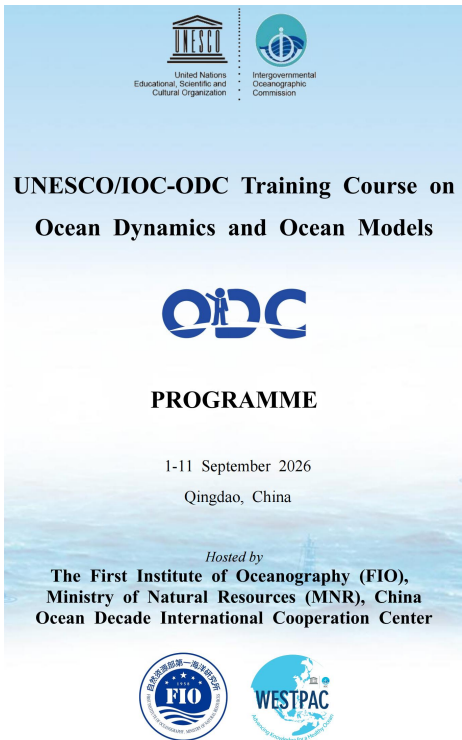




自然资源部第一海洋研究所

拓海探极 聚力创新

Automatic simulation system for marine environment --Clicks to build high-resolution regional ocean models for global region



Wan qing
万清

I won

青岛

Chi
迟

chicago

350018185@qq.com

自然资源部第一海洋研究所
First Institute of Oceanography, MNR



Ocean models are like cars. Some people study how to build cars, while others drive cars.

Building a programming environment is difficult. Many people are needed for assistance



- 1)HYCOM
- 2)ROMS
- 3)POM
- 4)ECOM
- 5)COHERENS
- 6)MITgcm
- 7)FVCOM
- 8)SCHISM



Still have to be able to do it yourself

After having a user interface, you can run the model with just a few clicks of the mouse



软件界面化

- 1)MIKE 21/3
- 2)Delft3D
- 3)EFDC
- 4)TELEMAC
- 5)ADCIRC





Clicks to Build Ocean Models

01 Methods and Data

02 Automatic simulation system

03 Show some results of our work

04 Dream



Clicks to Build Ocean Models



Part **1**

Methods and Data



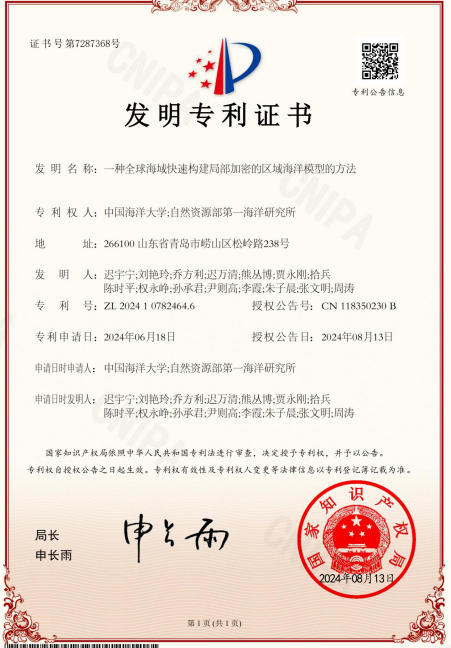
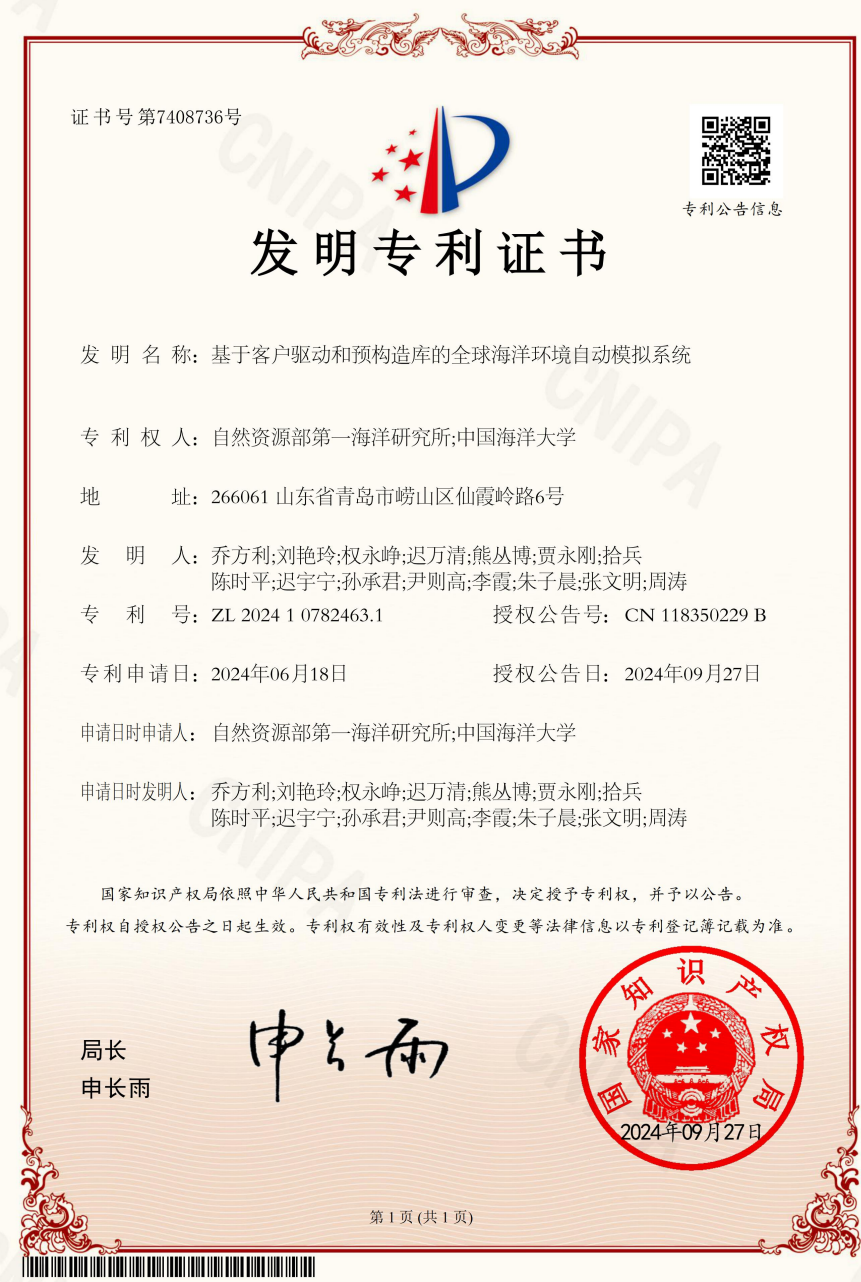
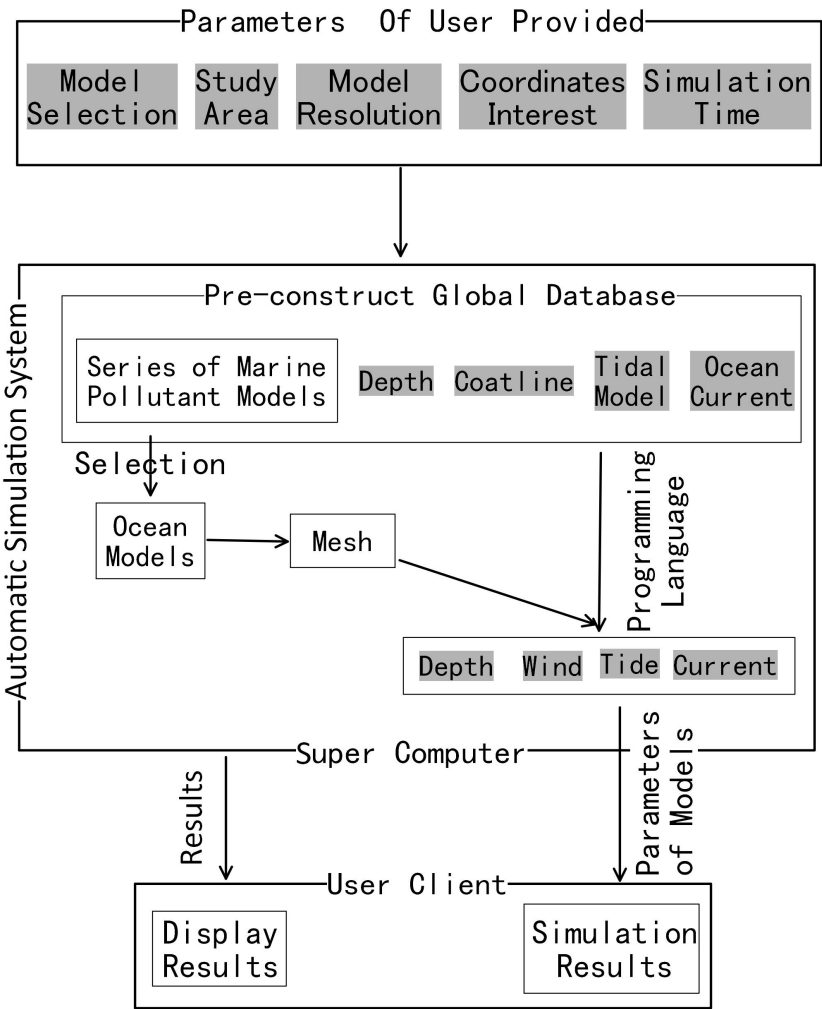
Methods and Data

USER

System

User

Methods



Led by Pro. Qiao and Chi



Topography

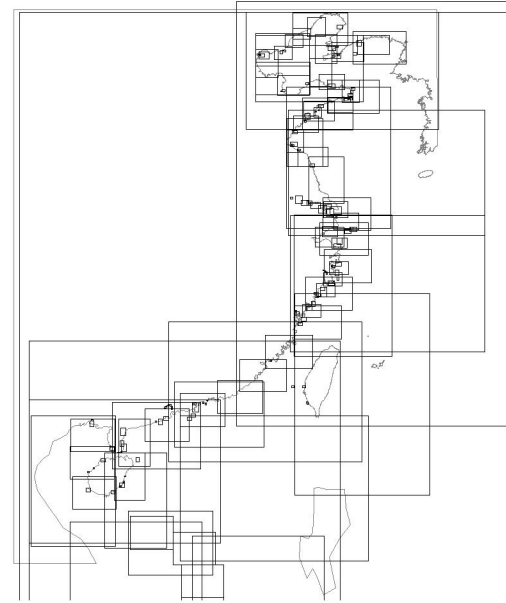
Wind

Tidal level

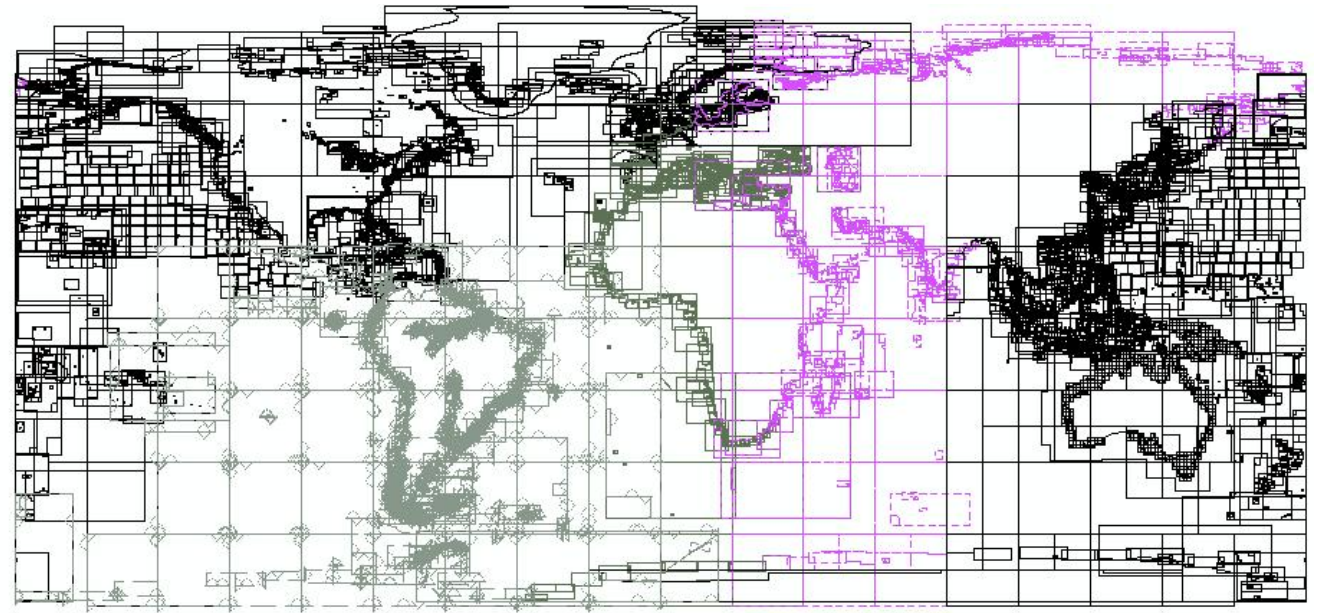
Ocean
Current

Temperature
Salinity

- (1) MIKE C-MAP electronic chart water depth data.
- (2) downloaded data such as ETOPO2022, gebco-2023, **SRTM15**, etc.
- (3) purchased electronic nautical charts of China and the United States.



	A	B	C	D	E	F	
1	图号	纬度起	纬度至	经度起	经度至	图名	注
2	10011	35.3000N	41.0000N	117.0000E	127.1500E	黄海北部及渤海	
3	10012	30.3000N	36.2400N	119.1500E	129.4000E	青岛上海至长崎	
4	10013	25.0000N	31.2500N	119.2036E	129.4036E	上海马尾至冲绳岛	
5	10014	18.1500N	27.4500N	119.3600E	126.4500E	台湾东、南部诸水道	
6	10015	19.5000N	26.2500N	112.5500E	123.1000E	福州至广州	
7	10016a	16.0000N	22.4500N	105.3000E	115.4000E	香港至海防	
8	10017	15.1000N	22.0000N	113.3000E	123.3000E	中沙群岛至巴士海峡	
9	10018	7.0000N	17.0000N	107.4000E	114.4000E	西沙群岛至南沙群岛	
10	10019a	6.2000N	16.2000N	114.1000E	121.1000E	黄岩岛至巴拉巴克海峡	
11	10020	0.5000N	11.0000N	103.0000E	110.0000E	金鼠角至纳土纳群岛	
12	10021	1.1000N	8.1000N	107.3000E	117.3000E	纳土纳群岛至巴拉巴克海峡	
13	101	13.0000S	50.0000N	99.0000E	148.0000E	中国海区及相邻海区	
14	102	3.0000N	41.0000N	105.0000E	133.0000E	中国海区	
179	15732	21.0300N	21.2415N	110.2130E	110.3715E	湛江港	
180	15761	20.3330N	20.4930N	110.1900E	110.3055E	东罗至外罗港	
181	15771	20.1812N	20.3930N	110.2345E	110.3930E	外罗水道	
182	15812	20.1708N	20.1850N	110.2048E	110.2440E	红坎湾	
183	15812	20.1410N	20.1645N	110.1112E	110.1700E	海安湾	
184	15812	20.1545N	20.1633N	110.1304E	110.1500E	海安湾	
185	16010	15.4500N	20.1500N	109.3000E	112.4900E	琼州海峡至西沙群岛	
186	16020	15.5000N	22.0000N	105.3500E	110.0500E	北部湾	
187	16100	18.0000N	20.1500N	110.0000E	111.3900E	抱虎角至陵水角	
188	16122	19.4900N	20.0200N	111.1030E	111.2000E	七洲列岛附近	
189	16162	19.0740N	19.1022N	110.3250E	110.3645E	博鳌港	
190	16162	18.5155N	18.5420N	110.2845E	110.3240E	城北港	
191	16171	18.3735N	18.4858N	110.1705E	110.3418E	城北港及大洲岛附近	
192	16171	18.3936N	18.4136N	110.1918E	110.2406E	城北港	
193	16300	17.3500N	19.0800N	107.4800E	110.0700E	陵水角至八所港	
194	16311	18.1635N	18.2800N	109.5110E	110.0525E	新村港附近	
195	16381	18.2305N	18.3425N	108.3235E	108.4900E	莺歌礁附近	
196	16500	19.0000N	20.3300N	107.4000E	110.0000E	八所港至南沙湾	
197	16532a	19.2903N	19.3305N	108.5250E	108.5835E	海头港	
198	16532b	19.1808N	19.2152N	108.3550E	108.4135E	昌化港	
199	16571	19.4920N	19.5830N	109.1900E	109.3250E	后水湾	
200	16621	20.2123N	20.3030N	109.4710E	110.0100E	南沙湾	
201	16632	20.3212N	20.3441N	109.4709E	109.5103E	乌石港	
202	16700	20.1900N	21.5100N	107.4200E	110.0300E	安铺港及附近	
203	16711	21.2900N	21.4500N	108.4335E	108.5530E	大风江口	
204	16771	21.4410N	21.4900N	108.4830E	108.5300E	大风江	
205	17010	14.3000N	17.0000N	110.4500E	115.1500E	西沙、中沙群岛	
206	17100	15.4200N	17.1500N	110.5100E	113.0800E	西沙群岛	
207	17300	15.5900N	16.3000N	113.0800E	115.2300E	中沙群岛	
208	17600	13.2700N	14.5900N	113.3500E	115.5000E	中南海沙附近	
209	17900	11.5500N	13.2700N	113.3500E	115.5000E	双子群岛北部	
210	18050	6.5500N	11.5700N	110.5000E	118.0000E	南沙群岛北、中部	





Topography

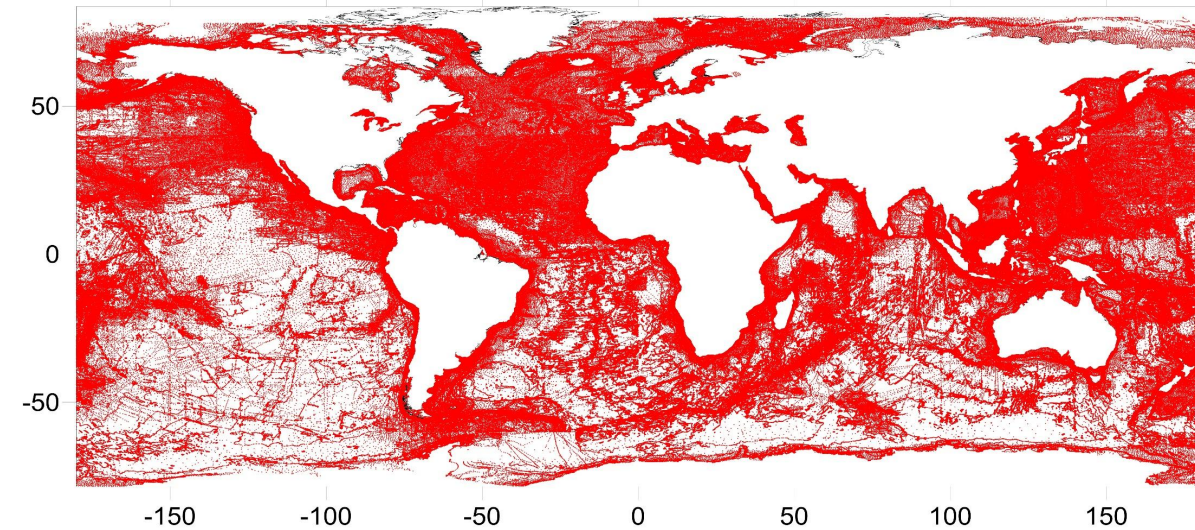
Wind

Tidal level

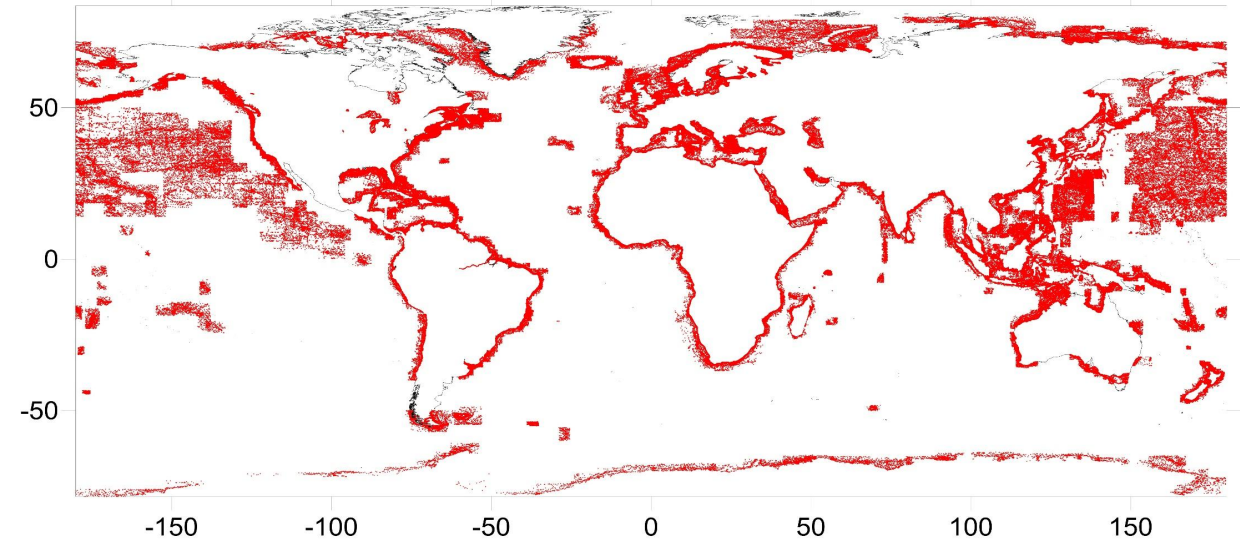
**Ocean
Curent**

**Temperature
Salinity**

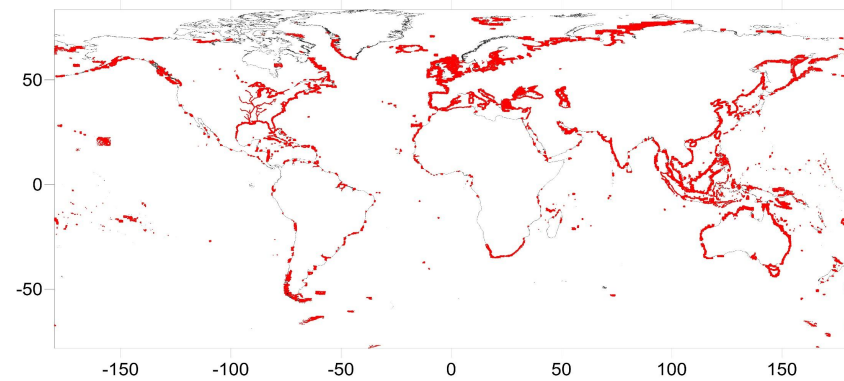
1:15,000,000 - 1:500,000



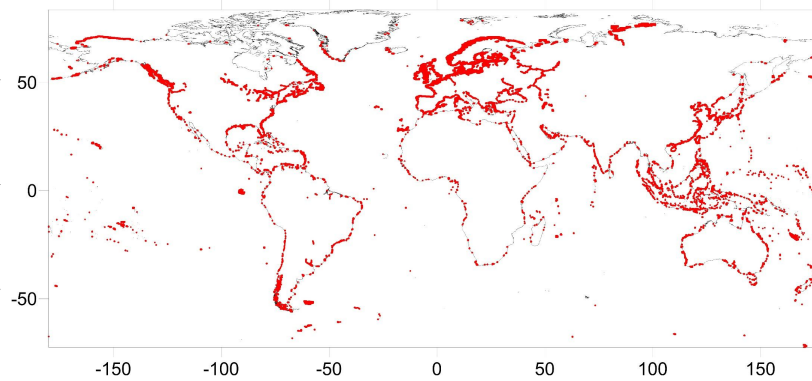
1:500,000-150,000



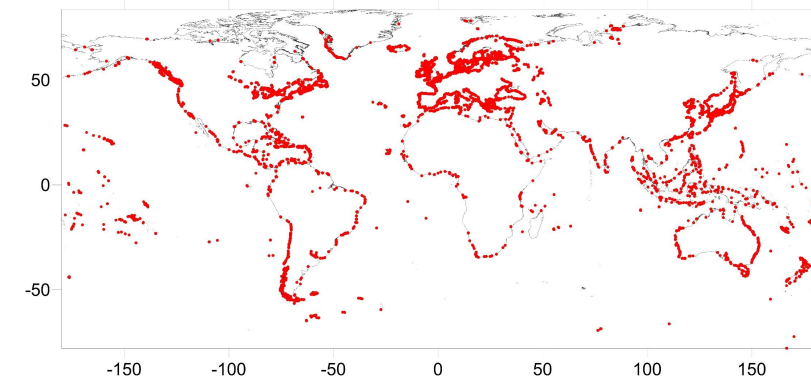
150,000-50,000



50,000-15,000



15,000-5,000





Topography

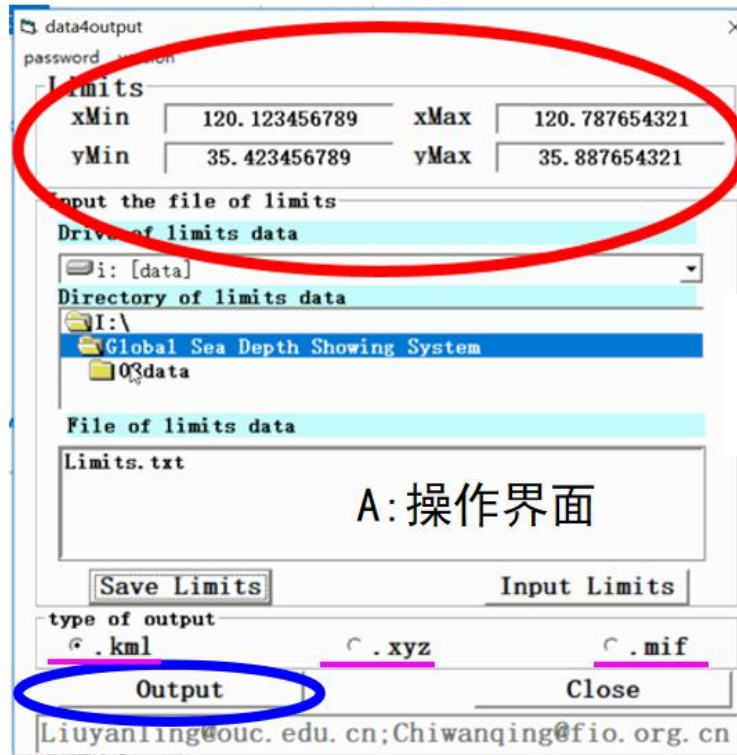
Wind

Tidal level

Ocean
Curent

Temperature
Salinity

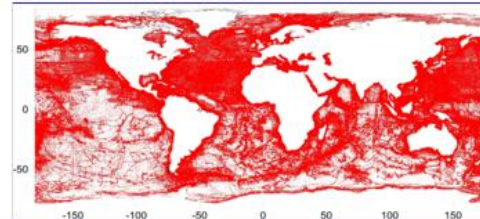
全球实测水深



有全球原始水深数据超过1744万条。

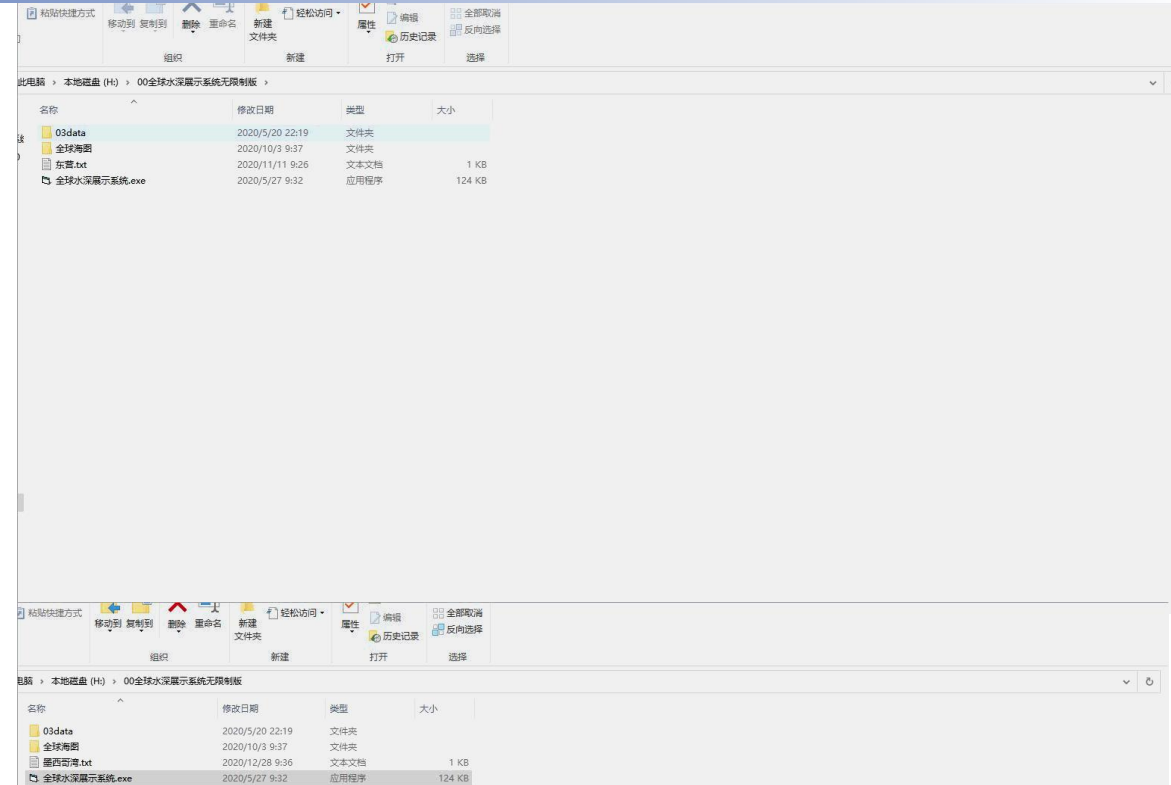


B: 软件著作权证书



C: 图中红色的点是水深点

开发的全球水深展示系统可以提取给定范围内的实测水深数据，本系统经济效益和社会效益前景良好，获得一项软件著作权。





Topography

Wind

Tidal level

Ocean
Current

Temperature
Salinity

1) European Centre for Medium-Range Weather Forecasts

f:\ECMWF010_NC\00NC*.*

文件名	↑扩展名大小	日期时间
UV010P194001	nc 4,634,716,620	2023/07/09 11:43
UV010P194002	nc 4,335,703,308	2023/07/09 12:02
UV010P194003	nc 4,634,716,620	2023/07/09 12:10
UV010P194004	nc 4,485,209,964	2023/07/09 12:16
UV010P194005	nc 4,634,716,620	2023/07/09 12:24
UV010P194006	nc 4,485,209,964	2023/07/09 12:44
UV010P194007	nc 4,634,716,620	2023/07/09 12:58
UV010P194008	nc 4,634,716,620	2023/07/09 13:01
UV010P194009	nc 4,485,209,964	2023/07/09 13:01
UV010P194010	nc 4,634,716,620	2023/07/09 13:17
UV010P194011	nc 4,485,209,964	2023/07/09 13:38
UV010P194012	nc 4,634,716,616	2023/07/09 13:53
UV010P194101	nc 4,634,716,624	2023/07/09 13:51
UV010P194102	nc 4,186,196,656	2023/07/09 13:53
UV010P194103	nc 4,634,716,620	2023/07/09 14:09
UV010P194104	nc 4,485,209,964	2023/07/09 14:42
UV010P194105	nc 4,634,716,616	2023/07/09 14:36
UV010P194106	nc 4,485,209,968	2023/07/09 14:34

f:\ECMWF010_NC\00NC*.*

文件名	↑扩展名大小	日期时间
UV010P202108	nc 4,634,716,616	2022/06/21 15:56
UV010P202109	nc 4,485,209,960	2022/06/21 16:57
UV010P202110	nc 4,634,716,616	2022/06/21 16:28
UV010P202111	nc 4,485,209,964	2022/07/25 17:22
UV010P202112	nc 4,634,716,616	2022/06/22 09:23
UV010P202201	nc 4,634,716,620	2023/12/22 17:50
UV010P202202	nc 4,186,196,652	2023/12/22 17:57
UV010P202203	nc 4,634,716,620	2023/12/22 18:10
UV010P202204	nc 4,485,209,964	2023/12/22 18:25
UV010P202205	nc 4,634,716,620	2023/12/22 18:36
UV010P202206	nc 4,485,209,964	2023/12/22 18:46
UV010P202207	nc 4,634,716,620	2023/12/22 18:47
UV010P202208	nc 4,634,716,624	2023/12/22 18:57
UV010P202209	nc 4,485,209,960	2023/12/22 19:10
UV010P202210	nc 4,634,716,620	2023/12/22 19:24
UV010P202211	nc 4,485,209,964	2023/12/22 19:25
UV010P202212	nc 4,634,716,620	2023/12/22 19:32
UV010P202301	nc 4,634,716,616	2023/12/22 19:40
UV010P202302	nc 4,186,196,656	2023/12/22 19:59
UV010P202303	nc 4,634,716,616	2023/12/22 20:05
UV010P202304	nc 4,485,209,964	2023/12/22 20:08
UV010P202305	nc 4,634,716,620	2023/12/22 20:18
UV010P202306	nc 4,485,209,968	2023/12/22 20:29
UV010P202307	nc 4,634,716,620	2023/12/22 20:46
UV010P202308	nc 4,634,716,620	2023/12/22 20:50
UV010P202309	nc 4,485,209,964	2023/12/22 20:50
UV010P202310	nc 4,634,716,620	2023/12/22 21:01
UV010P202311	nc 4,485,209,964	2023/12/22 21:06
UV010P202312	nc 2,466,870,108	2023/12/22 21:05



Topography

Wind

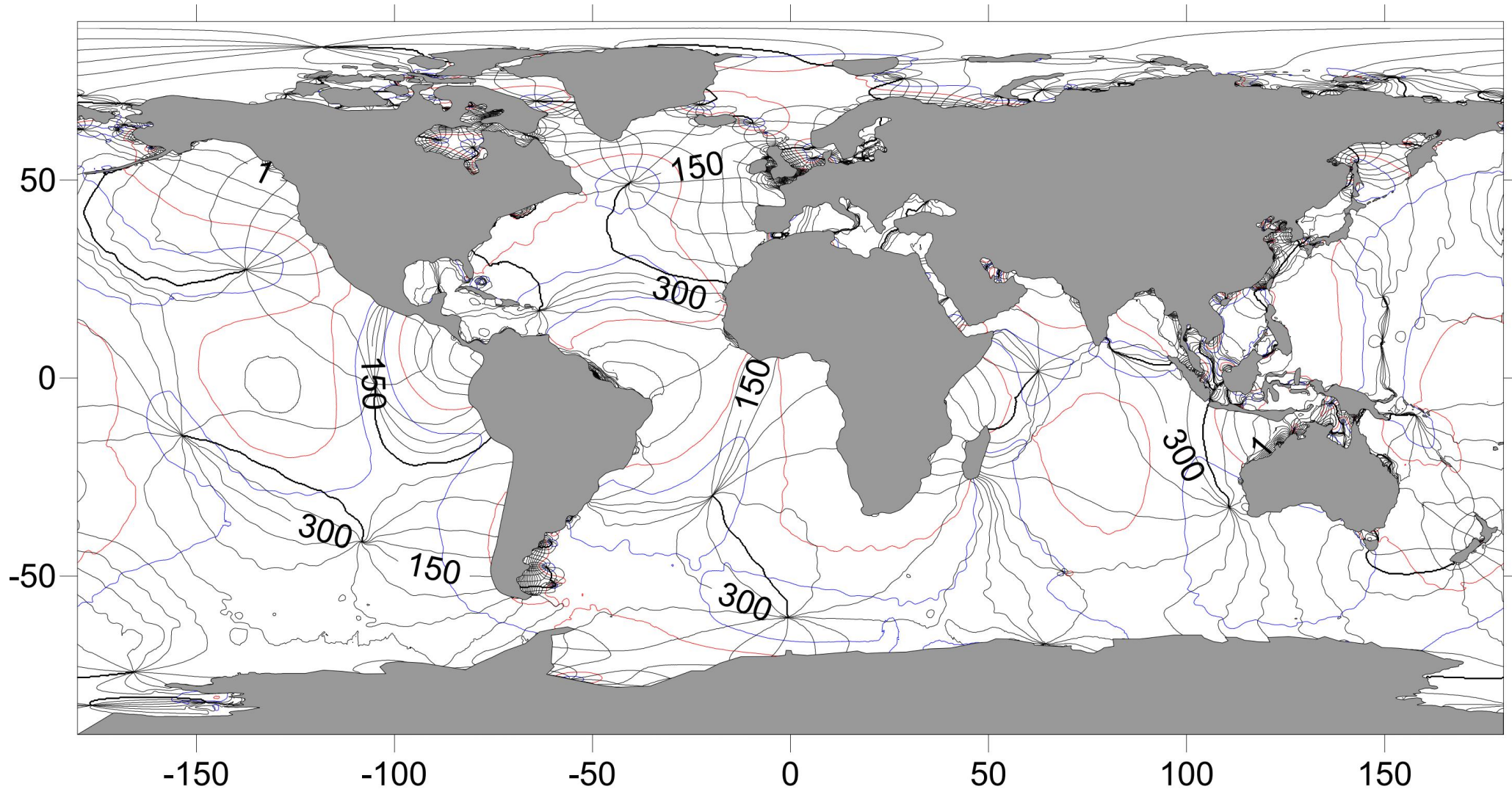
Tidal level

Ocean
Current

Temperature
Salinity

Using the global tidal model to get open boundary .

We now have
Tidal Prediction
for X Ocean
Global Tidal
Models (from
Oregon State
University)
and DHI-Mike
Global Tidal
Models





Topography

Wind

Tidal level

Ocean
Current

Temperature
Salinity

HyCOM has a relatively large amount of data, but the download speed is slow, so we did not use this data.

We use FIO-COM data for global ocean currents, temperature, and salinity.

FIO-COM is a program developed by the team led by Vice Director Qiao Fangli of the First Institute of Oceanography, MNR

y:\FIO-COM-res-2a*.*		
文件名	↑扩展名大小	日期时间
↑[.]	<DIR>	2024/01/26 16:00
📁[2019110512]	<DIR>	2024/01/20 16:53
📁[2019110612]	<DIR>	2024/01/20 16:44
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📁[2019110912]	<DIR>	2024/01/20 15:58
📁[2019111012]	<DIR>	2024/01/20 15:47
📁[2019111112]	<DIR>	2024/01/20 15:35
📁[2019111212]	<DIR>	2024/01/20 15:23
📁[2019111312]	<DIR>	2024/01/20 15:11
📁[2019111412]	<DIR>	2024/01/20 14:59
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📁[2019111912]	<DIR>	2024/01/20 14:01
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📁[2019112112]	<DIR>	2024/01/20 13:38
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📁[2019112312]	<DIR>	2024/01/20 13:14
📁[2019112412]	<DIR>	2024/01/20 13:03
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📁[2019112612]	<DIR>	2024/01/20 12:39
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📁[2019112812]	<DIR>	2024/01/20 12:15
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📁[2019113012]	<DIR>	2024/01/20 11:51
📁[2019120112]	<DIR>	2024/01/20 11:39
📁[2019120212]	<DIR>	2024/01/20 11:28
📁[2019120312]	<DIR>	2024/01/20 11:16



Clicks to Build Ocean Models



Part 2

Automatic simulation System for Ocean

<http://www.aiocean.online/>
<http://111.15.3.96:8999/#/>
47.99.236.26:8999



Function of Automatic simulation system for marine environment

← → ↻ ⚠ 不安全 | 47.105.56.91:8999/#/login

Canada's Online S... ★ QQ空间 U UNSV英语学习频... Downloading / Pri... 迟家宁 云南: 百房百车位... 国学网--国学入门 澎湃新闻-专注时政... 新建文件夹 CORMIX Mixing Z... Lakeview Cellars... banff门票 【选车工具|选车中... » 其他书签



环境影响数值模拟系统

Automatic simulation system for marine environment

User Login

 Account



 Password:8-16 characters

☐ Remember Password

Login

中文

English

Français

日本語

한국어

Bahasa Malaysia

Español

Русский

Deutsch

ภาษาไทย

Português

Danish

Italiano

Nederlands

Tiếng Việt

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Function of Automatic simulation system for marine environment

← → ↻ ⚠ 不安全 | 47.105.56.91:8999/#/login

Canada's Online S... ★ QQ空间 📺 UNSV英语学习频... ☁ Downloading / Pri... 📁 迟家宁 📺 云南: 百房百车位... 📡 国学网--国学入门 📰 澎湃新闻-专注时政... 📁 新建文件夹 🔄 CORMIX Mixing Z... 🏠 Lakeview Cellars... 📄 banff门票 📄 【选车工具】选车中... ➡ 📁 其他书签

🌐

环境影响数值模拟系统

Automatic simulation system for marine environment

User Login

 cwq001



☒ Remember Password

Login

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Function of Automatic simulation system for marine environment

← → ↻ ⚠ 不安全 | 47.105.56.91:8999/#/mock

Canada's Online S... ★ QQ空间 UNSV英语学习频... Downloading / Pri... 迟家宁 云南: 百房百车位... 国学网--国学入门 澎湃新闻-专注时政... 新建文件夹 CORMIX Mixing Z... Lakeview Cellars... banff门票 【选车工具|选车中... 其他书签

环境影响数值模拟系统

Simulation Visualization Result Projects

10:47:31
2025 08 22 Welcome,迟万清 Exit

Prompt
No automatic simulation data available, please go to "Project" to select or create one

No Project
Visualization
Result
Ruler

Start Simulation
Stop Simulation
Logs

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Function of Automatic simulation system for marine environment

← → ↻ ⚠ 不安全 | 47.105.56.91:8999/#/engineering 🔍 📄 ☆ 🗑 W ⋮

🌐 Canada's Online S... 🌟 QQ空间 📺 UNSV英语学习频... ☁ Downloading / Pri... 📁 迟家宁 📍 云南: 百房百车位... 📖 国学网--国学入门 📰 澎湃新闻-专注时政... 📁 新建文件夹 🔄 CORMIX Mixing Z... 🏠 Lakeview Cellars... 🎫 banfff门票 🚗 【选车工具】选车中... » 📁 其他书签

环境影响数值模拟系统

1 Projects

System

Back

10:47:31
2025 08 22 | • Welcome,迟万清 🌐 ⏻ Exit

Project name: Model type:

2 New project

☐	ID	Project name:	Model type:	Creation time	Update time	Created by	Auto Simulation	Status	Options
No Data									

Total 0 < 1 > Go to 1

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Function of Automatic simulation system for marine environment

环境影 响数值模拟系统

Projects System Back

Model Details

2025-08-24 00:00:00

* Time Step Length

1 Seconds

* Center point coordinates

5 119.90000 39.00000

* Simulation Range

6 560 km 440 km

* Mesh size

10 7 km

加密区半径 10 km

Confirm Cancel

type: Select model type

Model Details

Upload project information 下载模板

Upload

* Project name:

1 cwq001_20250822105003

* Model type:

水动力模型 2

* Start time

3 2025-08-22 00:00:00

* End time

4 2025-08-24 00:00:00

* Time Step Length

Creation time Update Simulation Status

Confirm Cancel

Model Details

加密区半径 10 km

加密网格尺寸 10 km

* Clip based on shoreline?

No Yes 8

* Compute Power

4 9 Core

* Sigma layering

3 10

11 Confirm Cancel

Total 0 1 Go to 1

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Function of Automatic simulation system for marine environment

Environment Impact Numerical Simulation System

Projects System Back

10:47:31 2025 08 22 Welcome,迟万清 Exit

Project name: Enter the project name Model type: Select model type

New project

ID	Project name:	Model type:	Creation time	Update	Simulation	Status	Options
----	---------------	-------------	---------------	--------	------------	--------	---------

Model Details

加密区半径 10 km

加密网格尺寸 10 km

网格生成中, 请稍等...

Clip based on shoreline?

No Yes

* Compute Power 4 Core

* Sigma layering 3

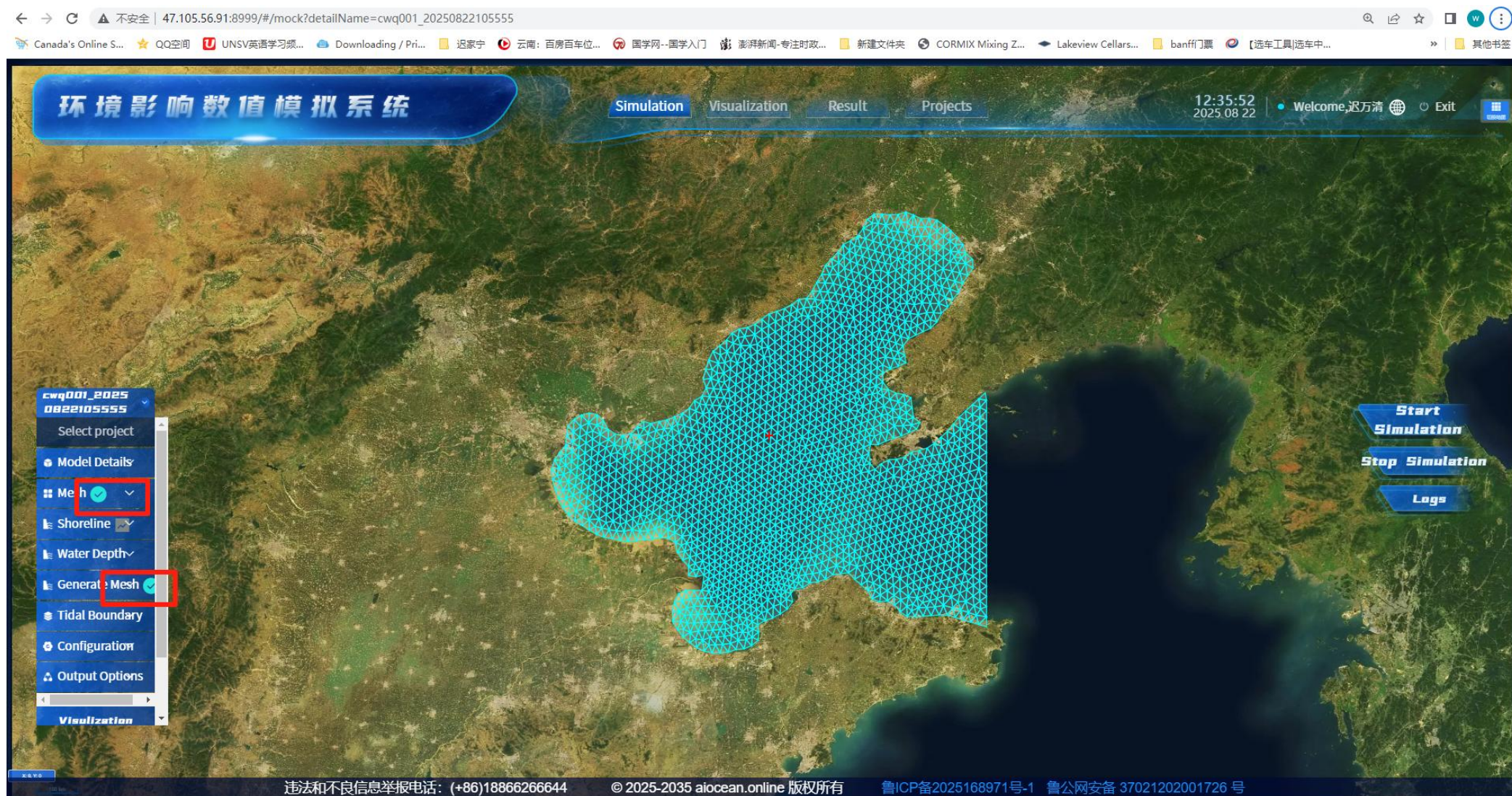
Confirm Cancel

Total 0 1 Go to 1

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Function of Automatic simulation System for Ocean





Function of Automatic simulation system for marine environment

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环境影响数值模拟系统

Simulation Visualization Result Projects

12:35:52 2025 08 22 • Welcome, 迟万清 🌐 ⏻ Exit

cwq001_2025 0822105555 ▼
Select project

🔧 Model Details

🔲 Mesh ☒ ▼

📏 Shoreline ☒

📏 Water Depth ☒

📏 Generate Mesh ☒

🌊 Tidal Boundary

⚙ Configuration

📄 Output Options

Visualization

Start Simulation

Stop Simulation

Logs

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Function of Automatic simulation system for marine environment

环境影 响数值模拟系统

Simulation Visualization Result Projects

13:44:38 2025.08.22 Welcome, 迟万清 Exit

Current project is running, center at: 119.90000000, 39.00000000

cwq001_2025 0822105555

Select project

Model Details

Model Details

Mesh

Shoreline

Water Depth

Generate Mesh

Tidal Boundary

Configuration

Hydrodynamic

Output Options

Hydrodynamic

0.8 1.00000000

Vertical diffusion coefficient 1.0000E-06 Inner-to-Outer Time Step Ratio 1

Vertical Diffusion Coefficient 1.00000000 Bottom Roughness 0.001

Minimum friction coefficient 0.005 Sigma Layering Form 3

Confirm Cancel

Hydrodynamic

0.8 1.00000000

Vertical diffusion coefficient 1.0000E-06 Inner-to-Outer Time Step Ratio 1

Vertical Diffusion Coefficient 1.00000000 Bottom Roughness 0.1

Minimum friction coefficient 0.1 Sigma Layering Form 3

Confirm Cancel

Start Simulation

Stop Simulation

Logs

Change Status

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Function of Automatic simulation system for marine environment

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环境影响数值模拟系统

Simulation Visualization Result Projects 13:44:38 2025-08-22 Welcome, 迟万清 Exit

Current project is running, center at: 119.90000000, 39.00000000

Hydrodynamic

0.8 1.00000000
Vertical diffusion coefficient Inner-to-Outer Time Step Ratio
1.0000E-06 1
Vertical Diffusion Coefficient Bottom Roughness
1.00000000 0.1
Minimum friction coefficient Sigma Layering Form
0.1 3

Confirm Cancel

Start Simulation
Stop Simulation
Logs
Change Status

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Function of Automatic simulation system for marine environment

Environment Impact Numerical Simulation System

Simulation Visualization Result Projects

13:44:38 2025-08-22 Welcome, 迟万清 Exit

Current project is running, center at: 119.90000000, 39.00000000

cwq001_2025 0822105555

Select project

Model Details

Model Details

Mesh

Shoreline

Water Depth

Generate Mesh

Tidal Boundary

Configuration

Hydrodynamic

Output Options

Start Simulation

Stop Simulation

Logs

Change Status

Stop Back

```
! 858 D000001T23:40: 0.000000 0000:00:00:00 0.0040 |=====|
! 859 D000001T23:43:20.000000 0000:00:00:00 0.0040 |=====|
! 860 D000001T23:46:40.000000 0000:00:00:00 0.0040 |=====|
! IINT SIMTIME FINISH IN SECS/IT PERCENT COMPLETE
! 861 D000001T23:50: 0.000000 0000:00:00:00 0.0040 |=====|
! 862 D000001T23:53:20.000000 0000:00:00:00 0.0040 |=====|
! 863 D000001T23:56:40.000000 0000:00:00:00 0.0040 |=====|
! 864 D000002T00:00: 0.000000 0000:00:00:00 0.0040 |=====|
! DUMPING DATA TO FILE: fio_0001: Record# 48
TADA!
tail: notify cannot be used, reverting to polling: Too many open files
```

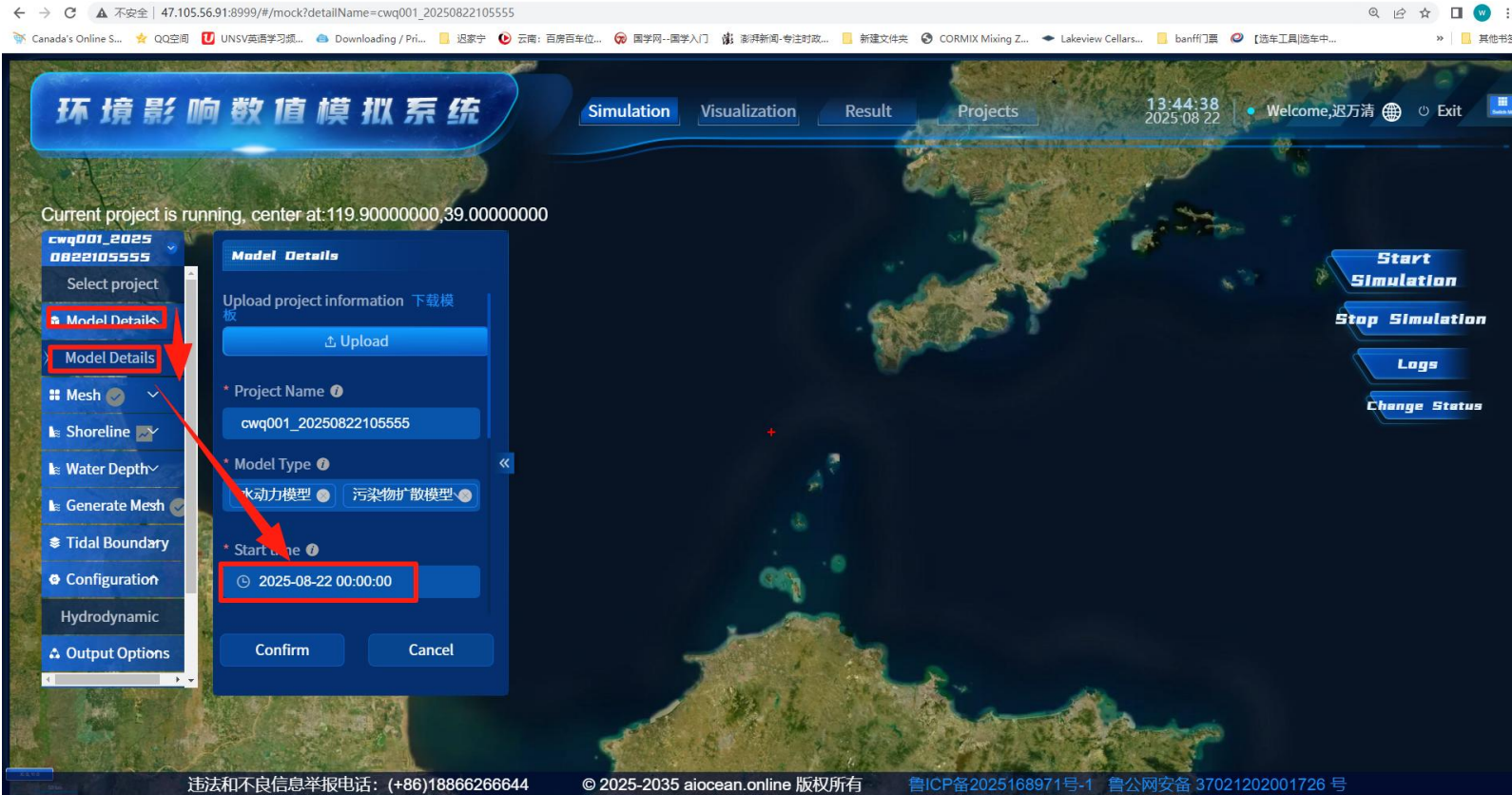
TADA!

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Function of Automatic simulation system for marine environment

This system can perform numerical simulations with just a few clicks, and allowing users to input parameters of Model Details, such as Start time, End time, center point coordinates, Simulation Range, and Mesh size, considered the coastline or not. The system can automatically load grids, open boundaries, and depth.





Function of Automatic simulation system for marine environment

```
fio_run.nal
0 10 20 30 40 50 60 70 80
1 !=====
2 !
3 !
4 !
5 !
6 !
7 !
8 !-- Beta Release
9 !
10 !
11 !=====DOMAIN DECOMPOSITION USING: METIS 4.0.1 =====
12 !=====Copyright 1998, Regents of University of Minnesota=====
13 !
14 &NML_CASE
15 CASE_TITLE = 'fio' !zcc mark
16 TIMEZONE = 'none',
17 START_DATE = 'days= 0.0', ! Define
18 END_DATE = 'days=16.', ! Define 1549800.0 774000.0
19 /
20 &NML_STARTUP
21 STARTUP_TYPE = 'coldstart',
22 STARTUP_FILE = 'none',
23 STARTUP_UV_TYPE = 'default',
24 STARTUP_TURB_TYPE = 'default',
25 STARTUP_TS_TYPE = 'constant',
26 STARTUP_T_VALS = 26 !26, ! Define
27 STARTUP_S_VALS = 26 !26, ! Define
28 STARTUP_U_VALS = -99.00000,
29 STARTUP_V_VALS = -99.00000,
30 STARTUP_DMAX = -99.00000, ! Define
31 /
32 &NML_IO
33 INPUT_DIR = './input',
34 OUTPUT_DIR = './output',
35 IREPORT = 100,
36 VISIT_ALL_VARS = F,
37 WAIT FOR VISIT = F,
```

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环境影响数值模拟系统

Simulation Visualization

Upload Hydrodynamic information
下载模板

Upload

Minimum Water Depth ⓘ	Horizontal diffusion coefficient ⓘ
0.05000000	0.2000000
Static Sea Surface Height Adjustment ⓘ	Horizontal PRANDTL Number ⓘ
0.8	1.00000000
Vertical diffusion coefficient ⓘ	Inner-to-Outer Time Step Ratio ⓘ
1.0000E-06	1
Confirm	Cancel

Model Details

Model Details

Mesh ✓ ▾

Shoreline ▾

Water Depth ▾

Generate Mesh ✓

Tidal Boundary

Configuration

Hydrodynamic

Dissolved Pollutant

Floating Pollutant

Suspended sediment

Suspended sediment details



Function of Automatic simulation system for marine environment



← → ↻ ⚠ 不安全 | 47.105.56.91:8999/#/mock?detailName=cwq001_20250822105555

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环境影响数值模拟系统

Pollution discharge start time

🕒 2025-08-22 00:00:00

🕒 2025-08-24 00:00:00

Half-saturation concentration of decay

0.5

Decay period

0.1 d-1

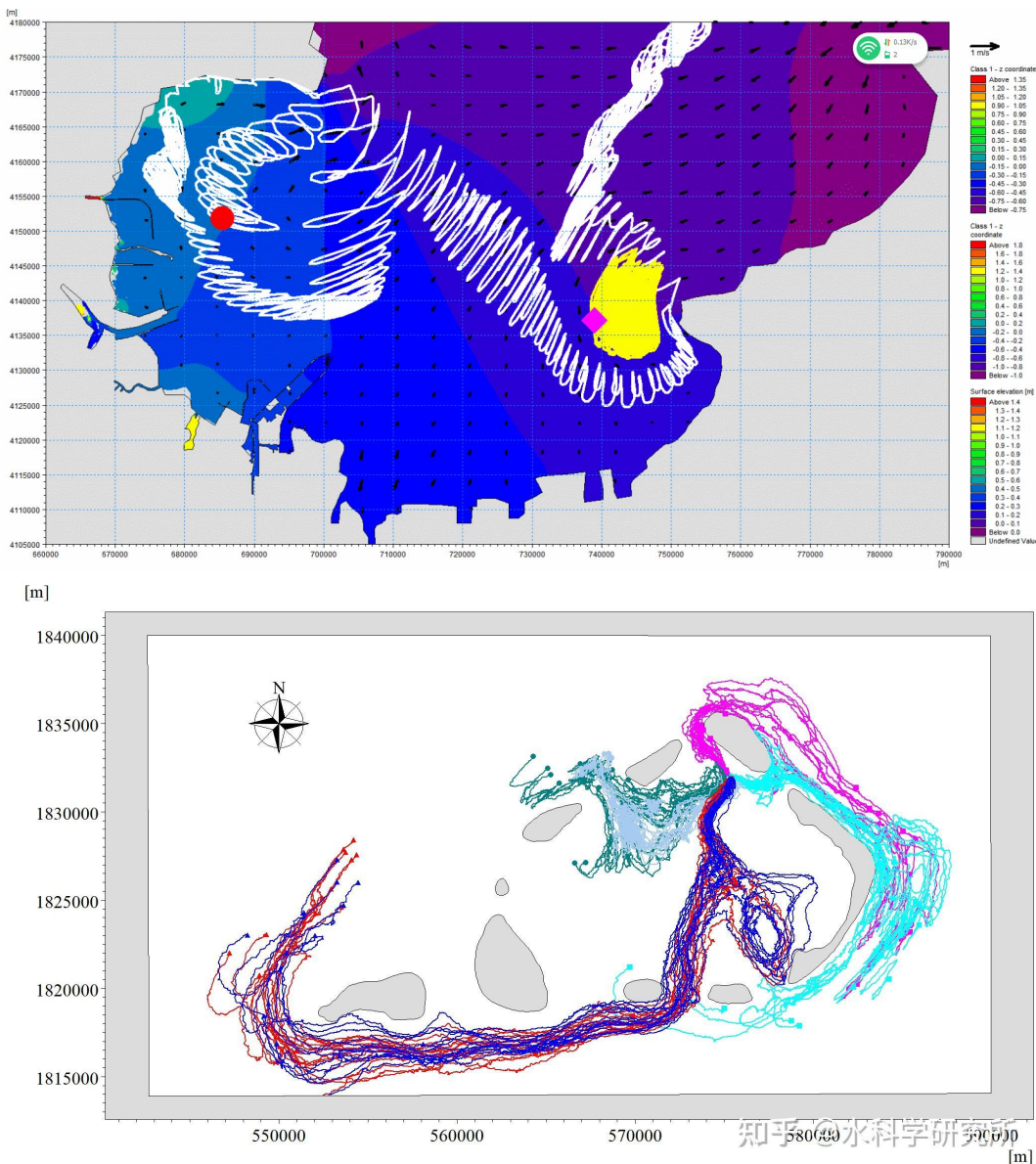
Dye layer [Select all](#) ⓘ

Confirm Cancel

- Model Details
- Model Details
- Mesh ☒ ▾
- Shoreline ☒ ▾
- Water Depth ▾
- Generate Mesh ☒
- Tidal Boundary
- Configuration
- Hydrodynamic
- Dissolved Pollutant**
- Floating Pollutant
- Suspended sediment
- Suspended sediment details



Function of Automatic simulation system for marine environment



Environment Impact Numerical Simulation System

Simulation Visualization

Model Details

Mesh

Shoreline

Water Depth

Generate Mesh

Tidal Boundary

Configuration

Hydrodynamic

Dissolved Pollutant

Floating Pollutant

Suspended sediment

Suspended sediment data

Upload

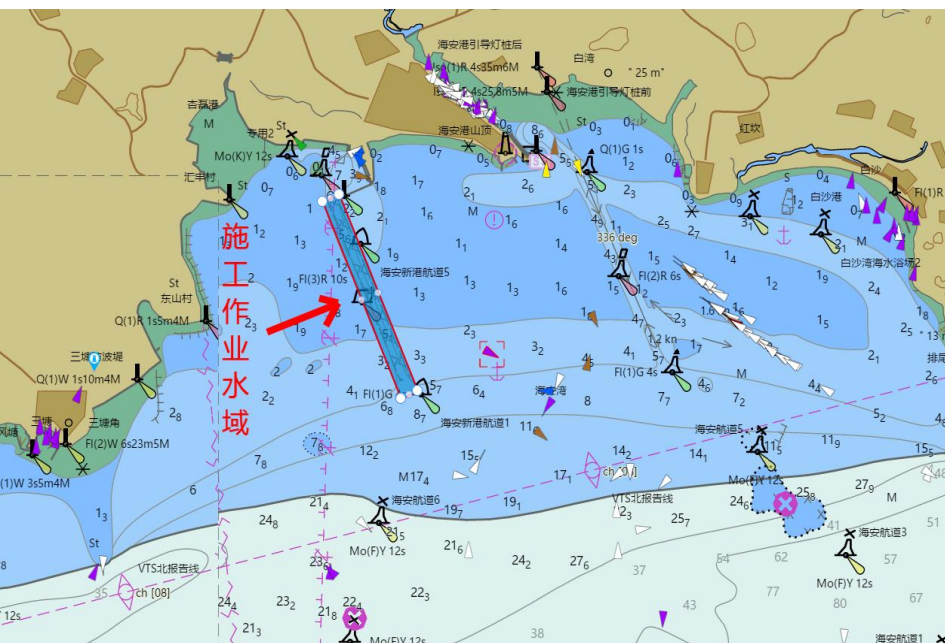
Download template

Export

Index	Release Coor...	Release Coor...	Release Coor...	Release Time	Calculat
1	759327.428...	4323883.26...	0	0	2



Function of Automatic simulation system for marine environment



环境影响数值模拟系统

admin_20250
831113520

Water Depth
Generate Mesh
Tidal Boundary
Configuration
Hydrodynamic
Dissolved Pollutant
Floating Pollutant
Suspended sediment
Suspended sediment details
Output Options

Suspended sediment details

Upload Download template Export

Index	Source name	Longitude	Latitude
1	工程点	119.99562072753906	39.02555465698242



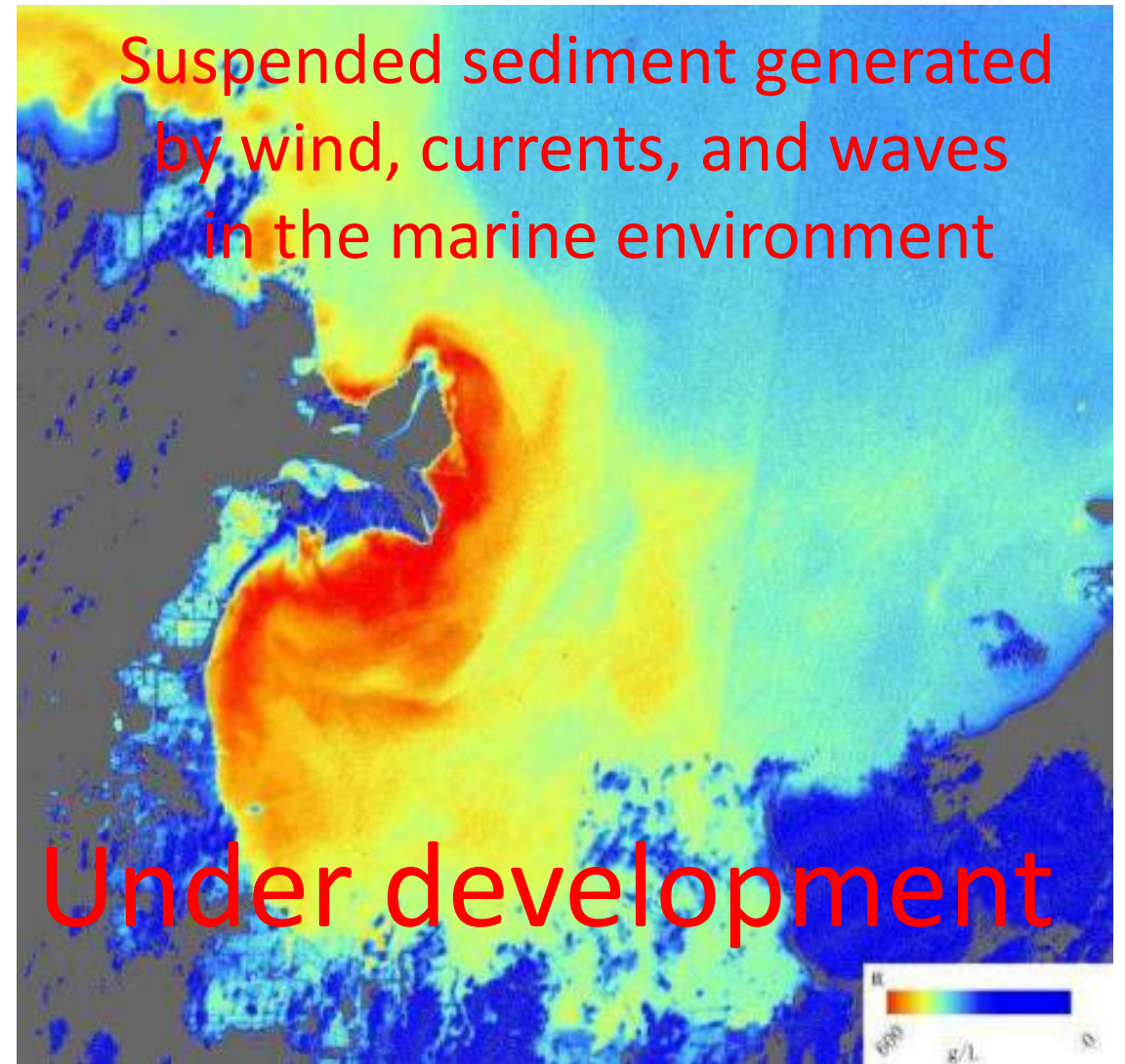
Function of Automatic simulation system for marine environment

Suspended sediment generated
by engineering construction



tidal currents

Suspended sediment generated
by wind, currents, and waves
in the marine environment



Under development

comparing the results of our system and DHI Mike

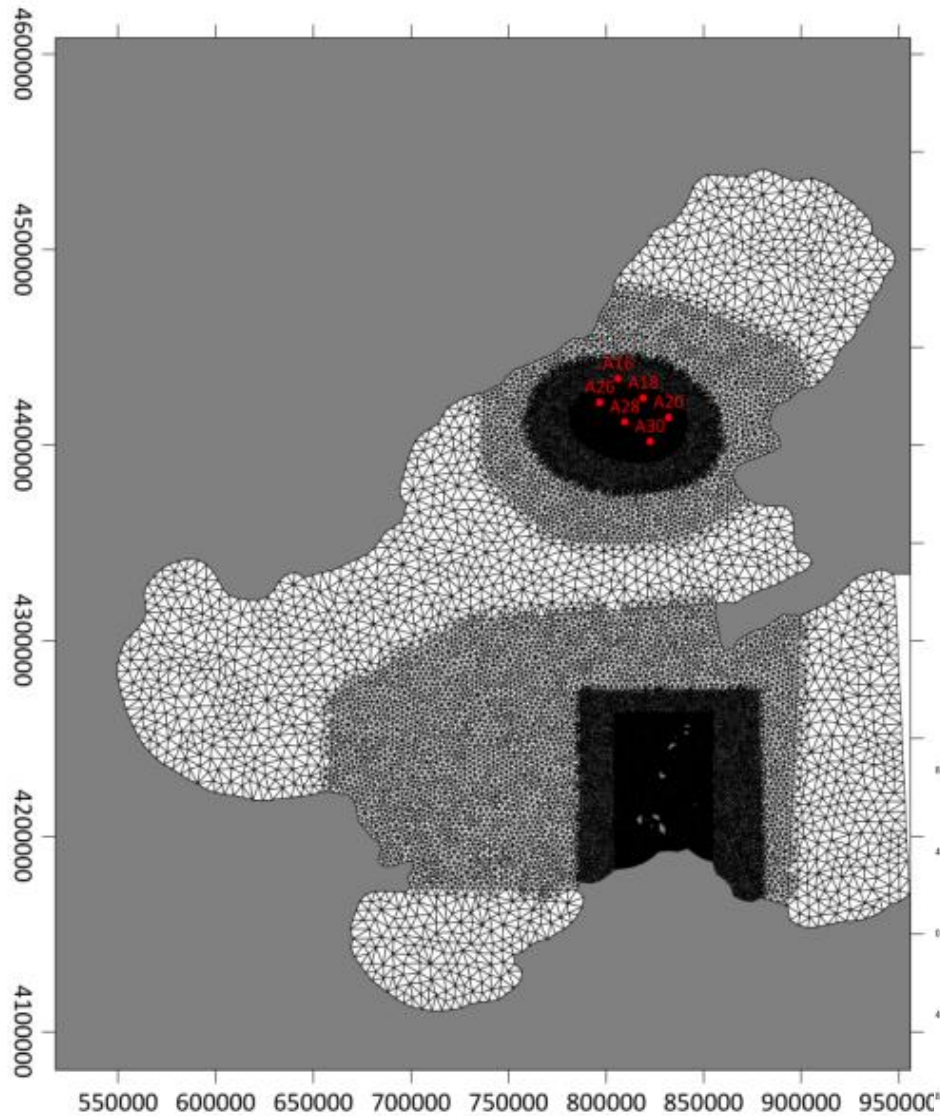


图 2.3-1 模型验证点位分布图

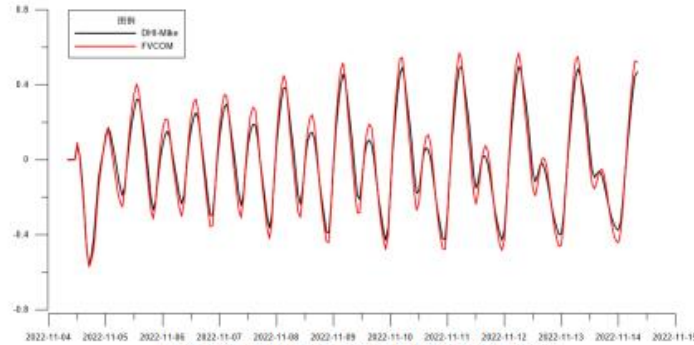


图 2.3-2 两模型在 A16 站位模拟潮位比较图

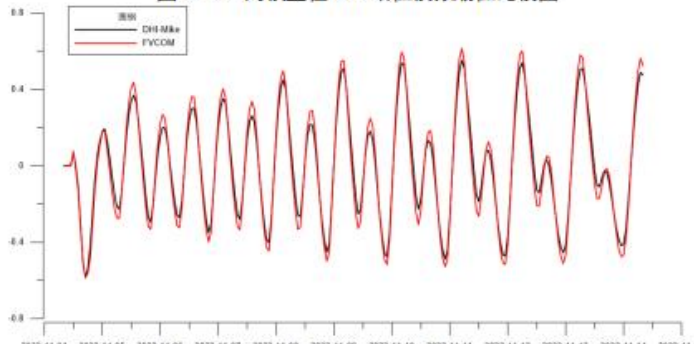


图 2.3-3 两模型在 A18 站位模拟潮位比较图

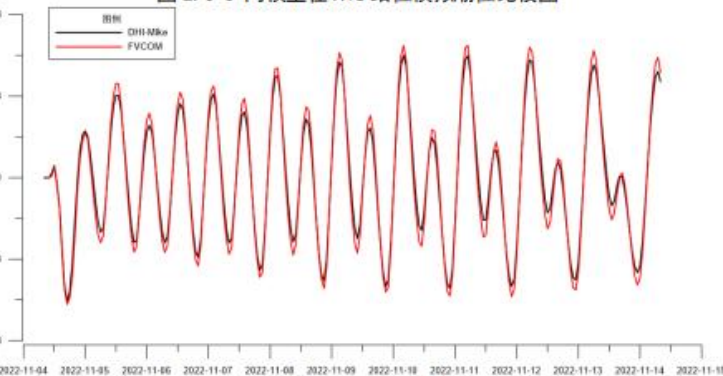


图 2.3-4 两模型在 A20 站位模拟潮位比较图

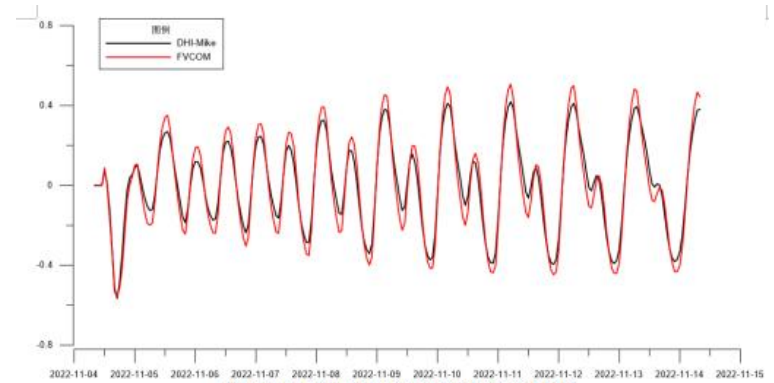


图 2.3-5 两模型在 A26 站位模拟潮位比较图

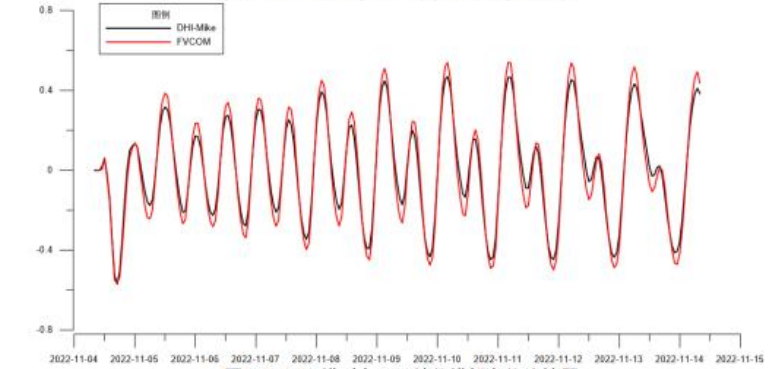


图 2.3-6 两模型在 A28 站位模拟潮位比较图

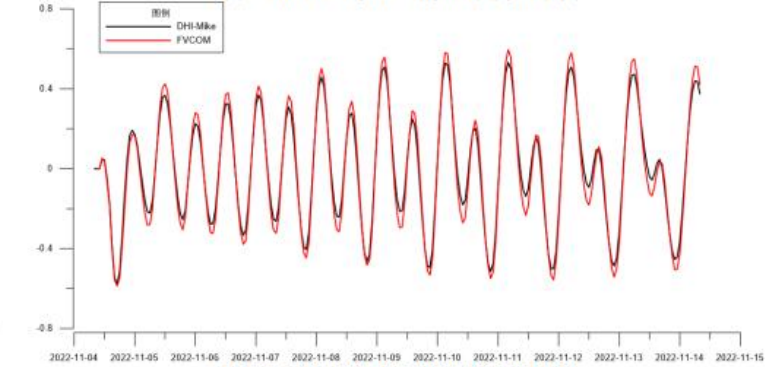


图 2.3-7 两模型在 A30 站位模拟潮位比较图

comparing the results of our system and DHI Mike

It can be seen that there is not much difference in flow direction between the two models at different positions, and the rising and falling tide patterns are basically the same. The consistency of flow velocity fluctuations is good, and the simulation results of DHI Mike are generally slightly larger than those of our system.

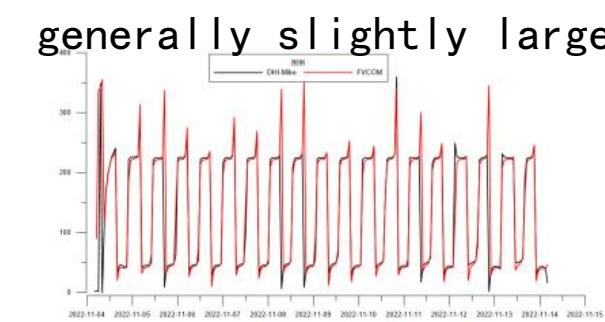


图 2.3-10 两模型在A16站位模拟流向比较图

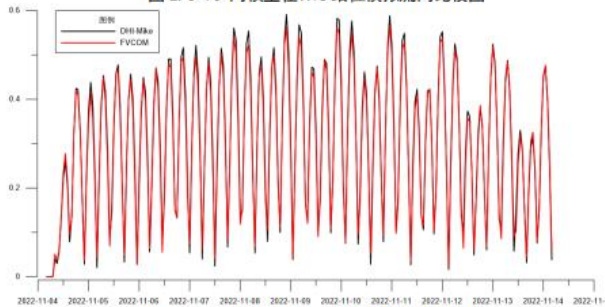


图 2.3-11 两模型在A16站位模拟流速比较图

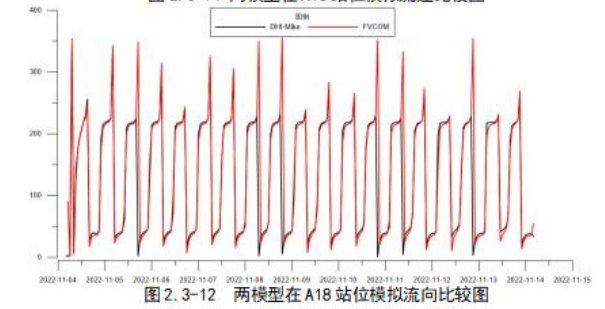


图 2.3-12 两模型在A18站位模拟流向比较图

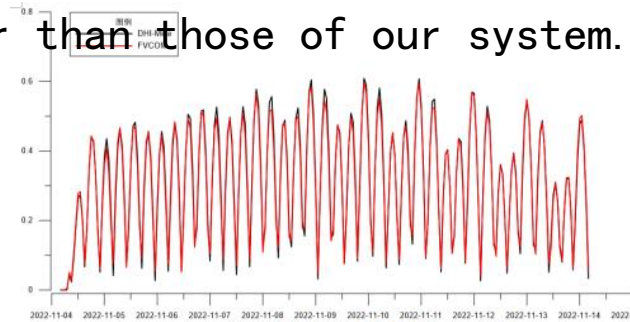


图 2.3-13 两模型在A18站位模拟流速比较图

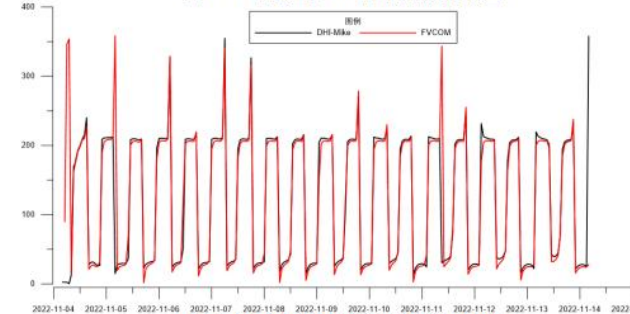


图 2.3-14 两模型在A20站位模拟流向比较图

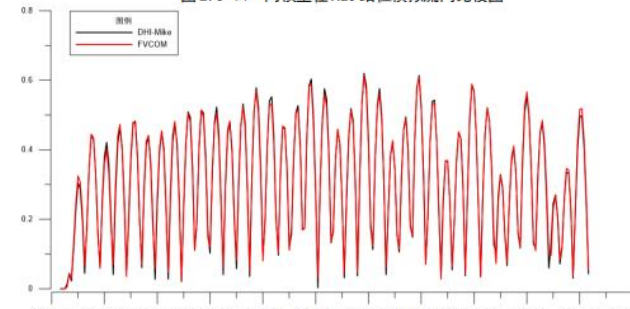


图 2.3-15 两模型在A20站位模拟流速比较图

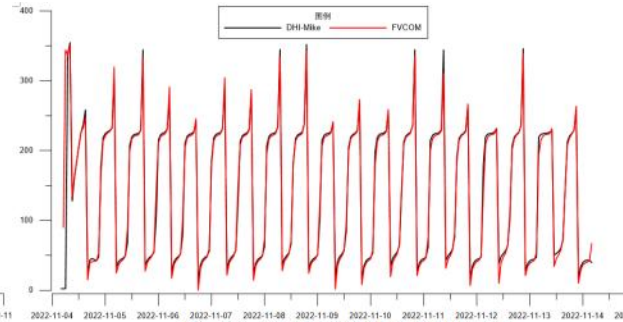


图 2.3-16 两模型在A26站位模拟流向比较图

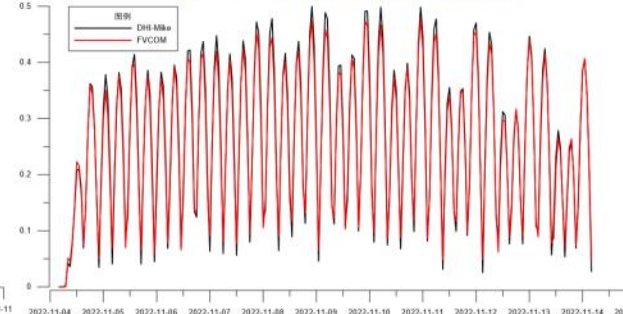


图 2.3-17 两模型在A26站位模拟流速比较图

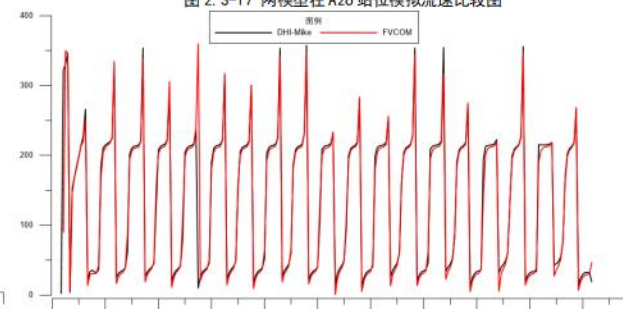


图 2.3-18 两模型在A28站位模拟流向比较图

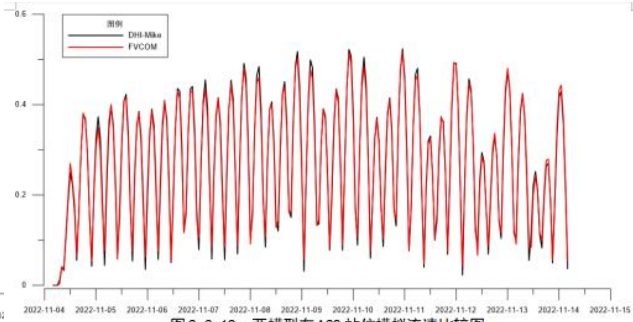


图 2.3-19 两模型在A28站位模拟流速比较图

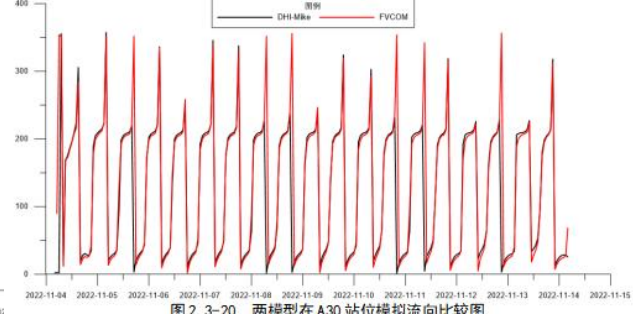


图 2.3-20 两模型在A30站位模拟流向比较图

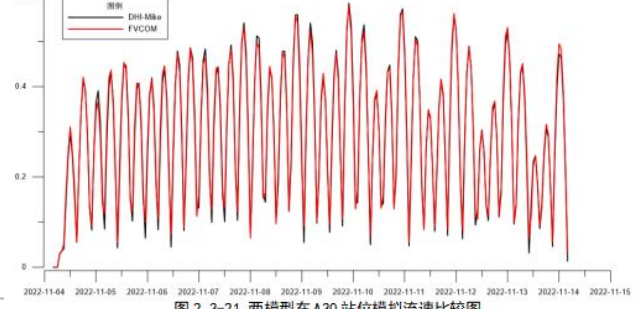


图 2.3-21 两模型在A30站位模拟流速比较图

comparing the results of our system and DHI Mike

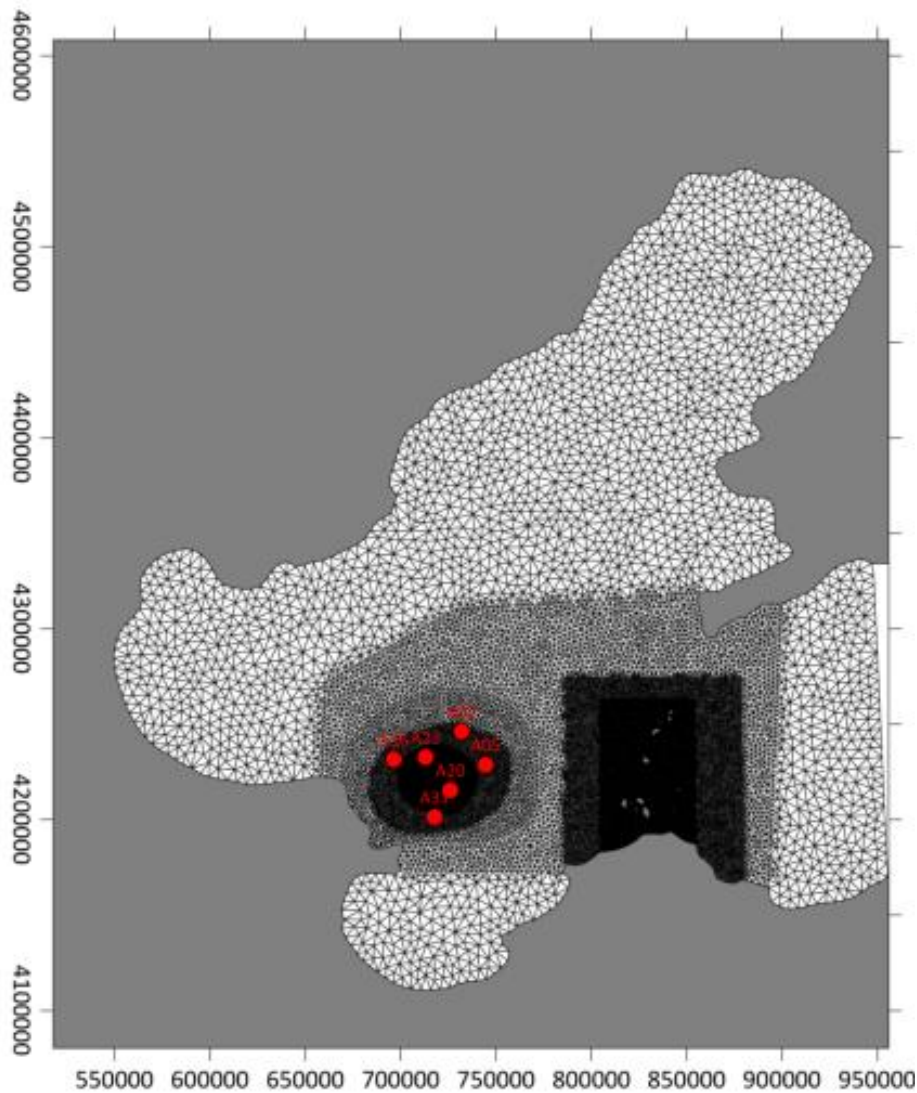


图 2.4-1 模型验证点位分布图

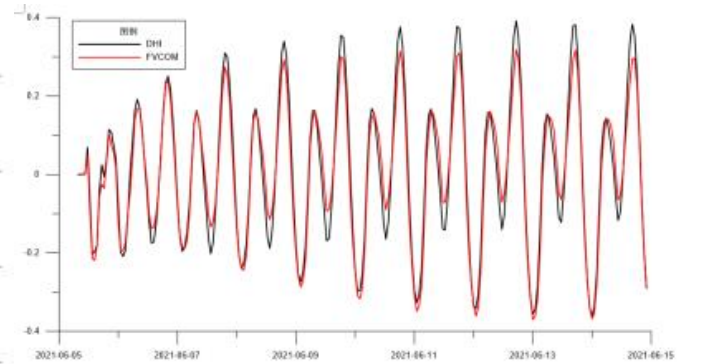


图 2.4-2 两模型在 A02 站位模拟潮位比较图

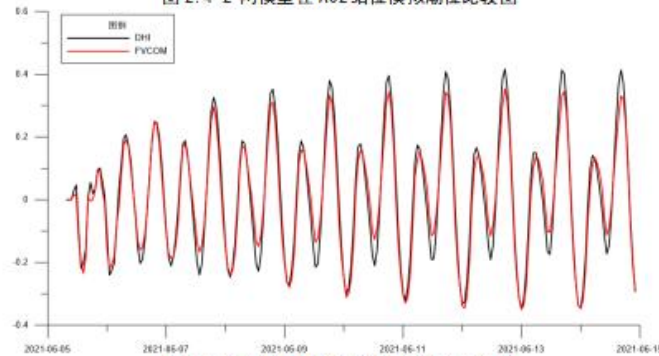


图 2.4-3 两模型在 A05 站位模拟潮位比较图

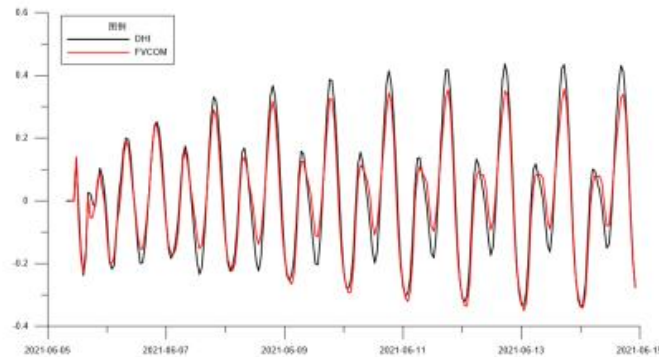


图 2.4-4 两模型在 A20 站位模拟潮位比较图

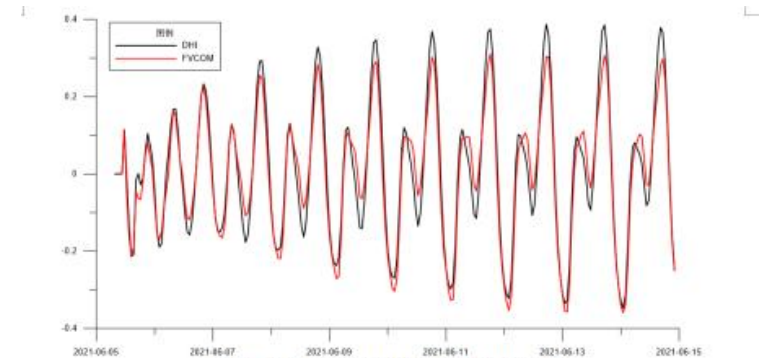


图 2.4-5 两模型在 A23 站位模拟潮位比较图

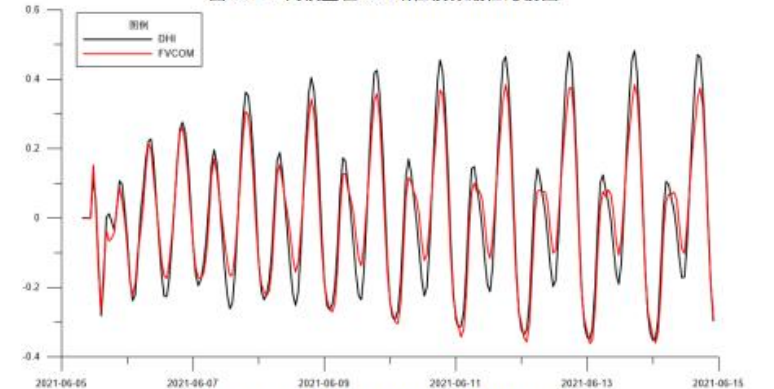


图 2.4-6 两模型在 A31 站位模拟潮位比较图

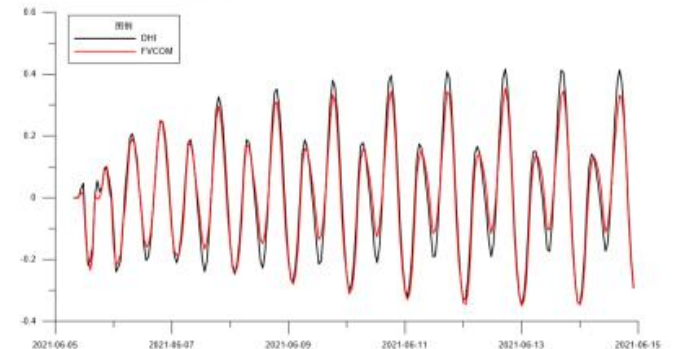


图 2.4-7 两模型在 A20 站位模拟潮位比较图



comparing the results of our system and DHI Mike

The comparison of the flow velocity and direction of these 6 stations shows that there are significant differences in the simulation results of the two models at some locations.

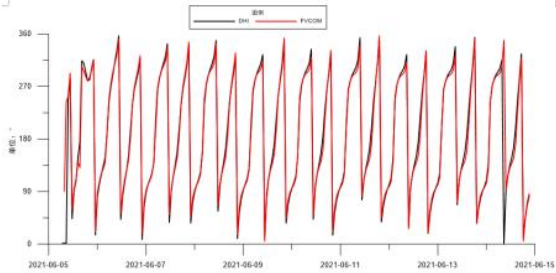


图 2.4-10 两模型在 A02 站位模拟流向比较图

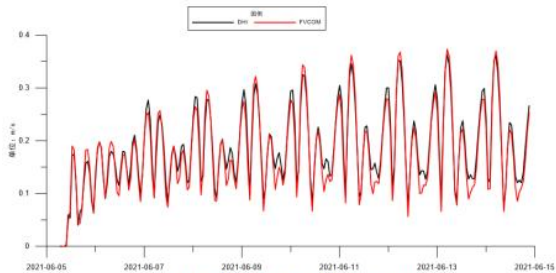


图 2.4-11 两模型在 A02 站位模拟流速比较图

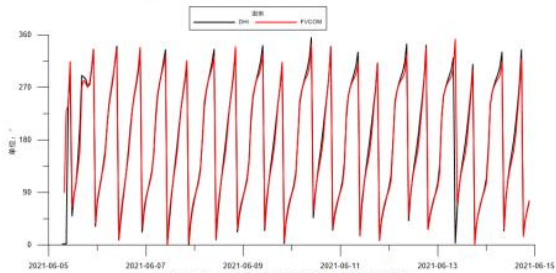


图 2.4-12 两模型在 A05 站位模拟流向比较图

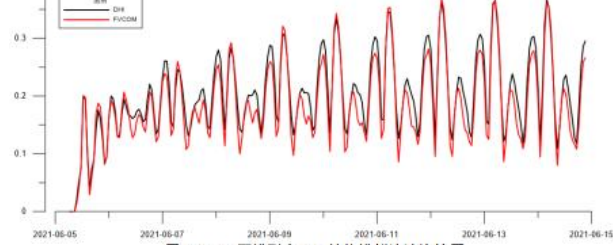


图 2.4-13 两模型在 A05 站位模拟流速比较图

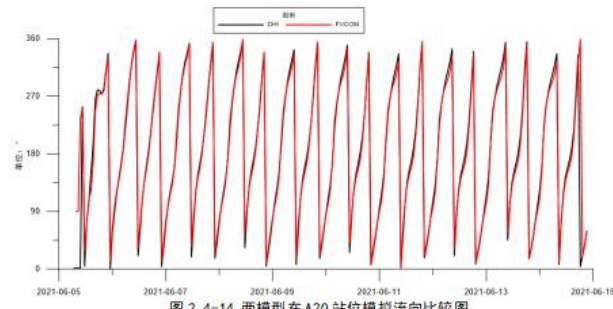


图 2.4-14 两模型在 A20 站位模拟流向比较图

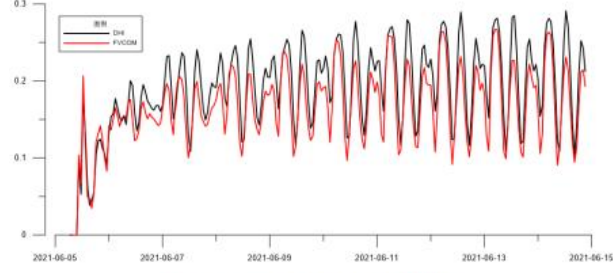


图 2.4-15 两模型在 A20 站位模拟流速比较图

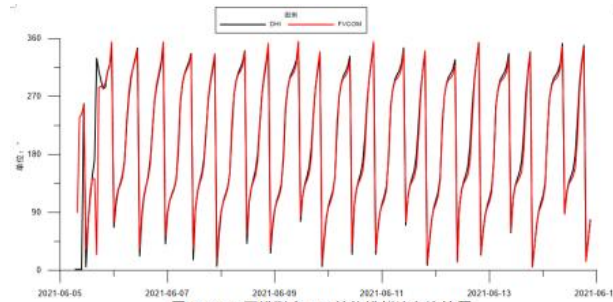


图 2.4-16 两模型在 A23 站位模拟流向比较图

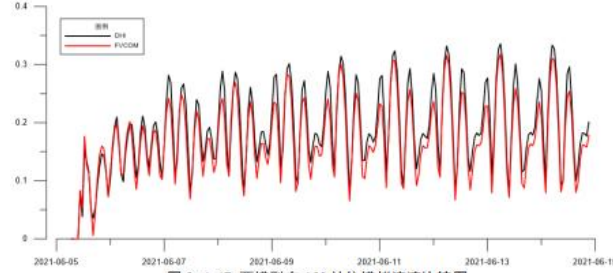


图 2.4-17 两模型在 A23 站位模拟流速比较图

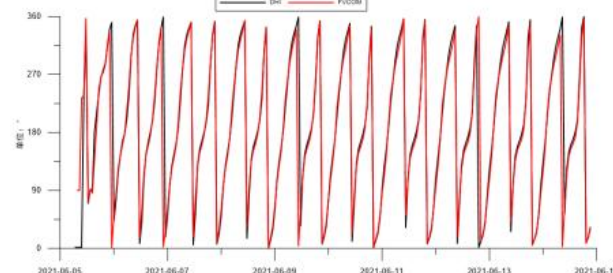


图 2.4-18 两模型在 A31 站位模拟流向比较图

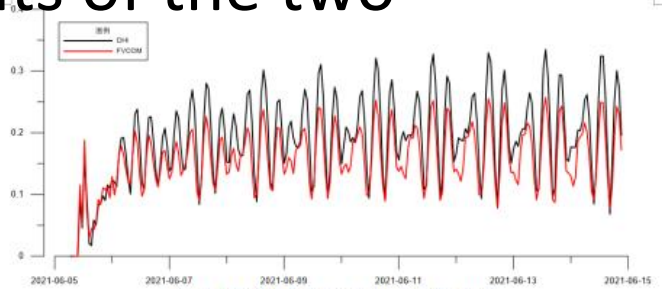


图 2.4-19 两模型在 A31 站位模拟流速比较图

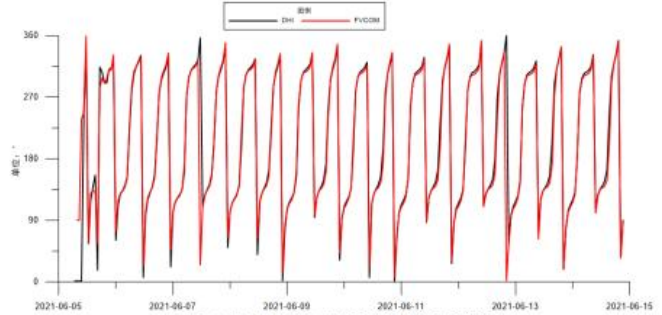


图 2.4-20 两模型在 A36 站位模拟流向比较图

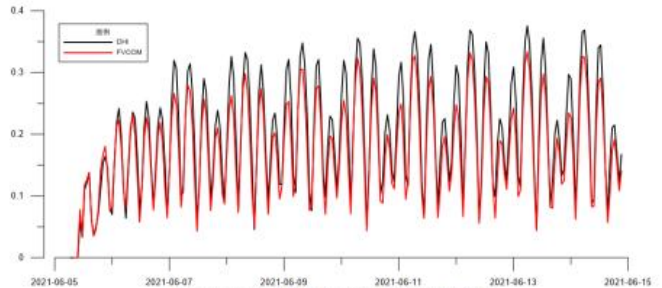
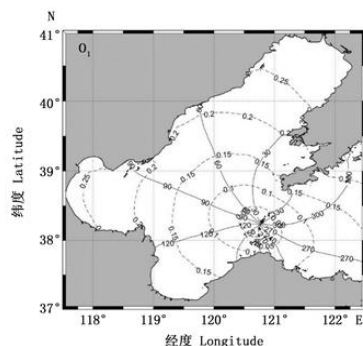
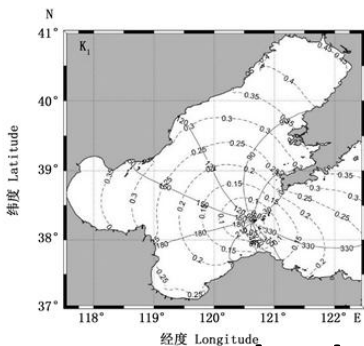
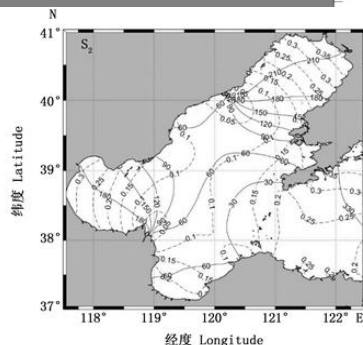
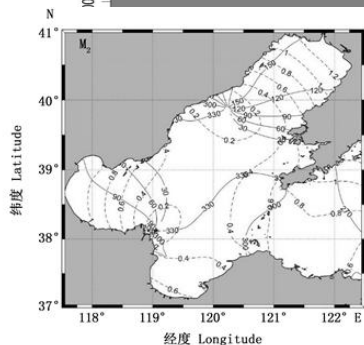
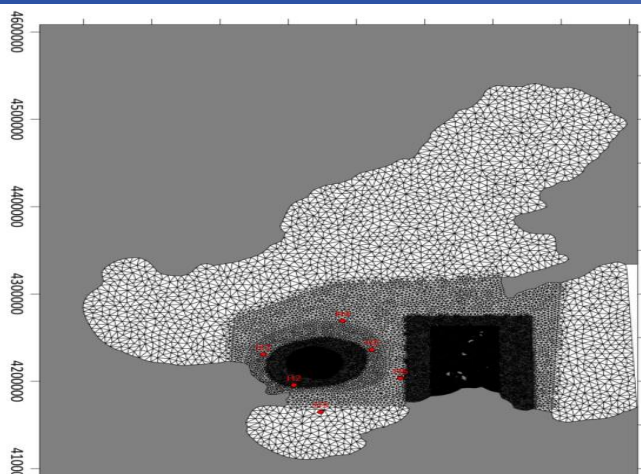


图 2.4-21 两模型在 A36 站位模拟流速比较图

comparing the results of our system and DHI Mike



amphidromic point

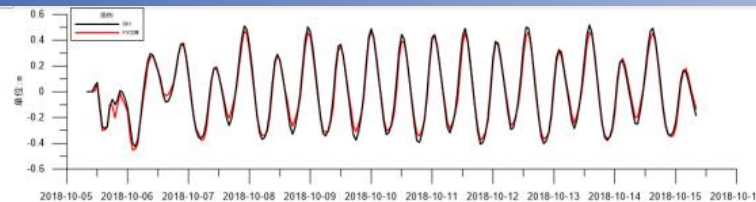


图 2.5-2 两模型在 H01 站位模拟潮位比较图

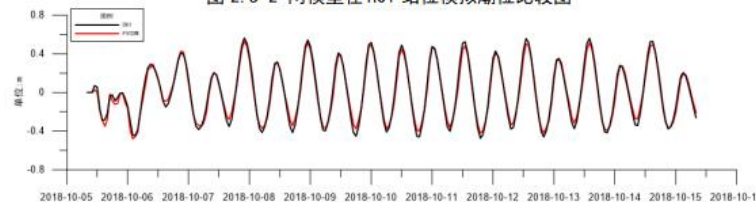


图 2.5-3 两模型在 H02 站位模拟潮位比较图

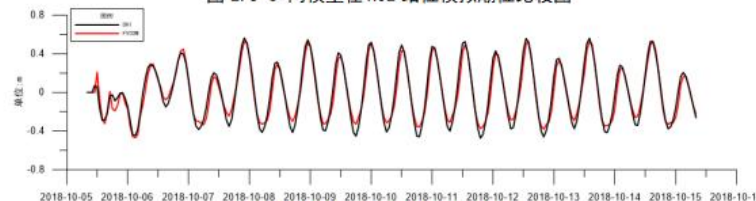


图 2.5-4 两模型在 H03 站位模拟潮位比较图

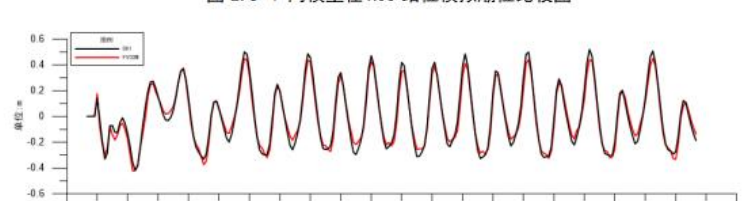


图 2.5-5 两模型在 H04 站位模拟潮位比较图

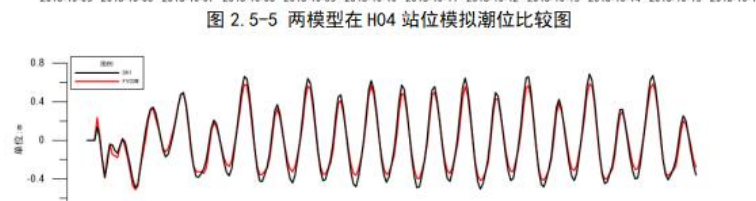


图 2.5-6 两模型在 H05 站位模拟潮位比较图

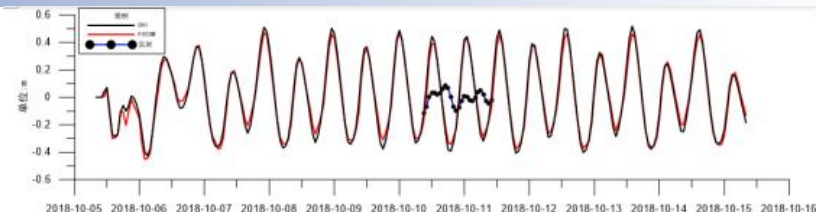


图 2.5-8 两模型在 H01 站位模拟潮位与实测潮位比较图

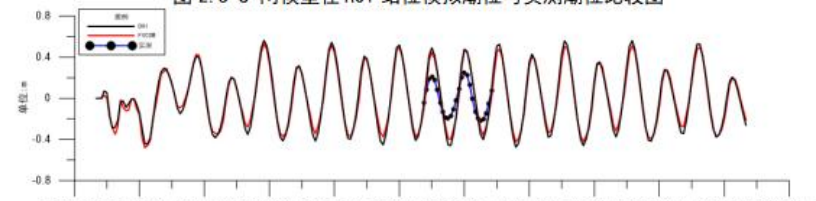


图 2.5-9 两模型在 H02 站位模拟潮位与实测潮位比较图

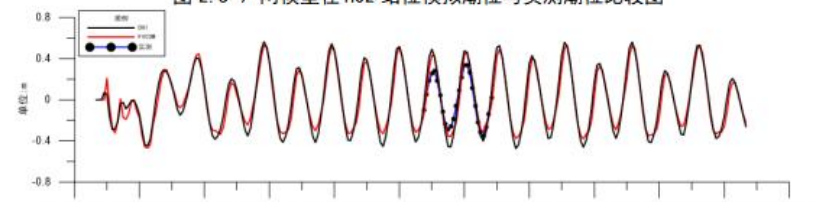


图 2.5-10 两模型在 H03 站位模拟潮位与实测潮位比较图

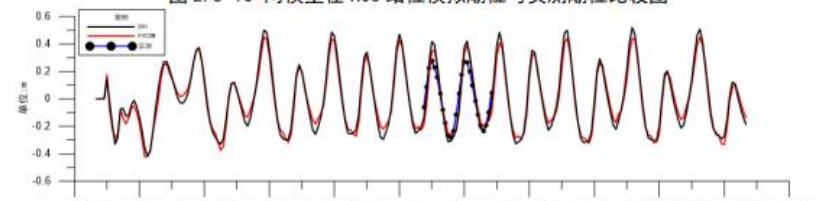


图 2.5-11 两模型在 H04 站位模拟潮位与实测潮位比较图

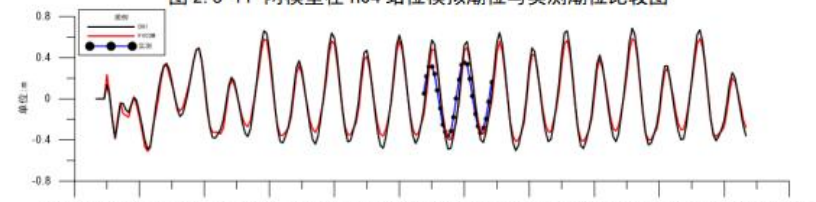


图 2.5-12 两模型在 H05 站位模拟潮位与实测潮位比较图

comparing the results of our system and DHI Mike

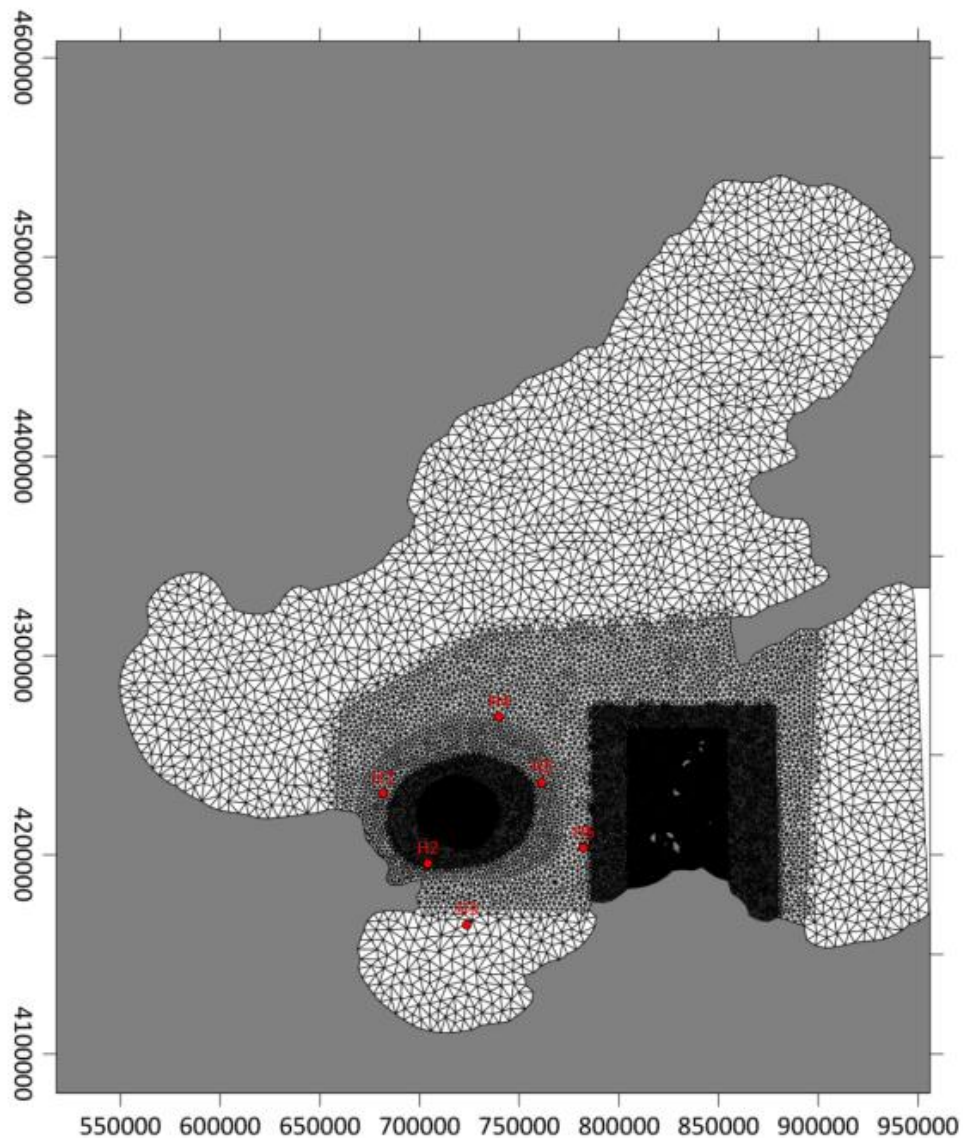


图 2.5-1 模型验证点位分布图

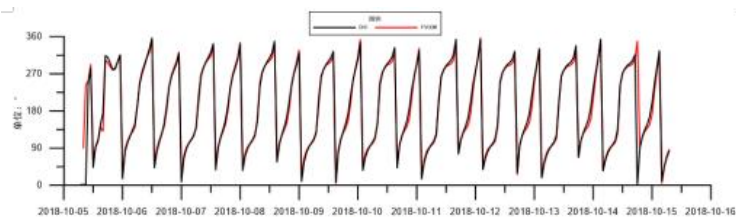


图 2.5-14 两模型在 H01 站位模拟流向比较图

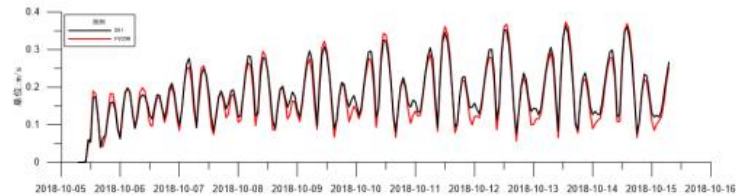


图 2.5-15 两模型在 H01 站位模拟流速比较图

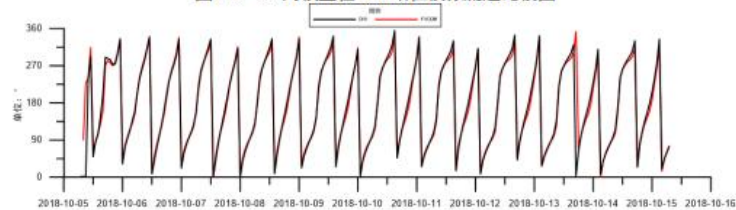


图 2.5-16 两模型在 H02 站位模拟流向比较图

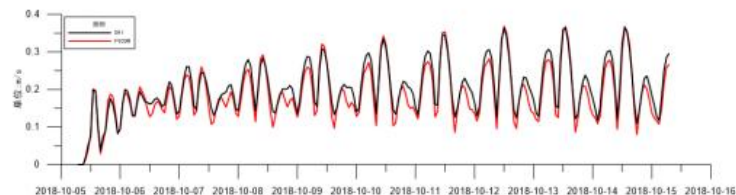


图 2.5-17 两模型在 H02 站位模拟流速比较图

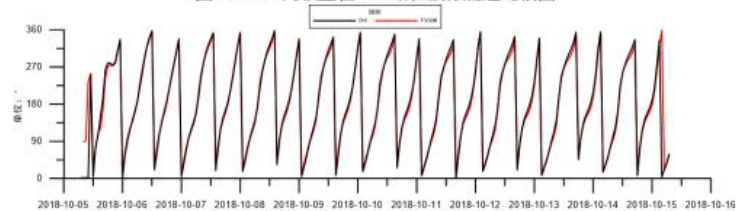


图 2.5-18 两模型在 H03 站位模拟流向比较图

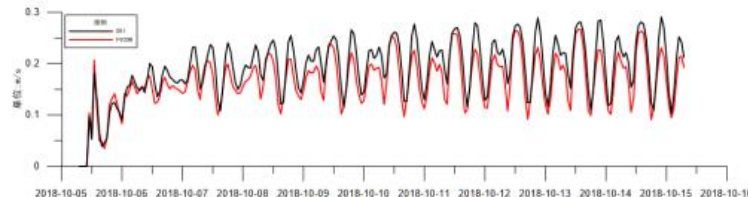


图 2.5-19 两模型在 H03 站位模拟流速比较图

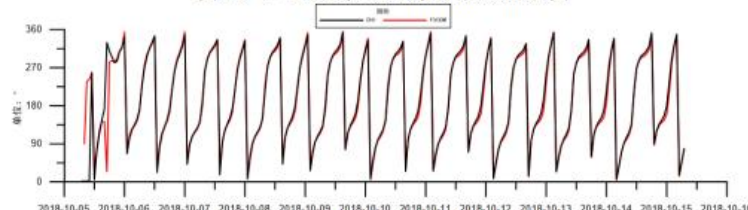


图 2.5-20 两模型在 H04 站位模拟流向比较图

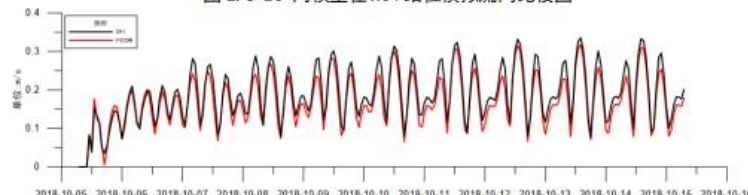


图 2.5-21 两模型在 H04 站位模拟流速比较图

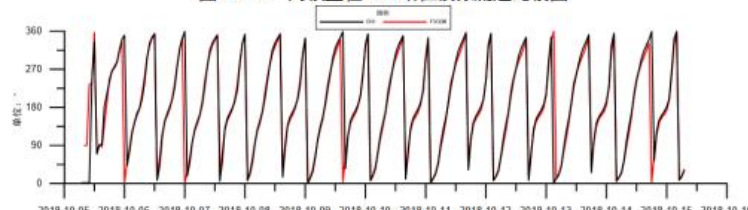


图 2.5-22 两模型在 H05 站位模拟流向比较图

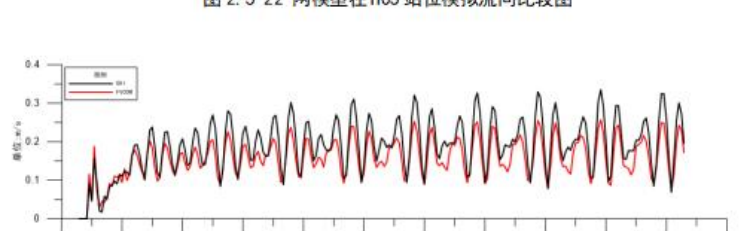


图 2.5-23 两模型在 H05 站位模拟流速比较图



comparing the results of our system and DHI Mike

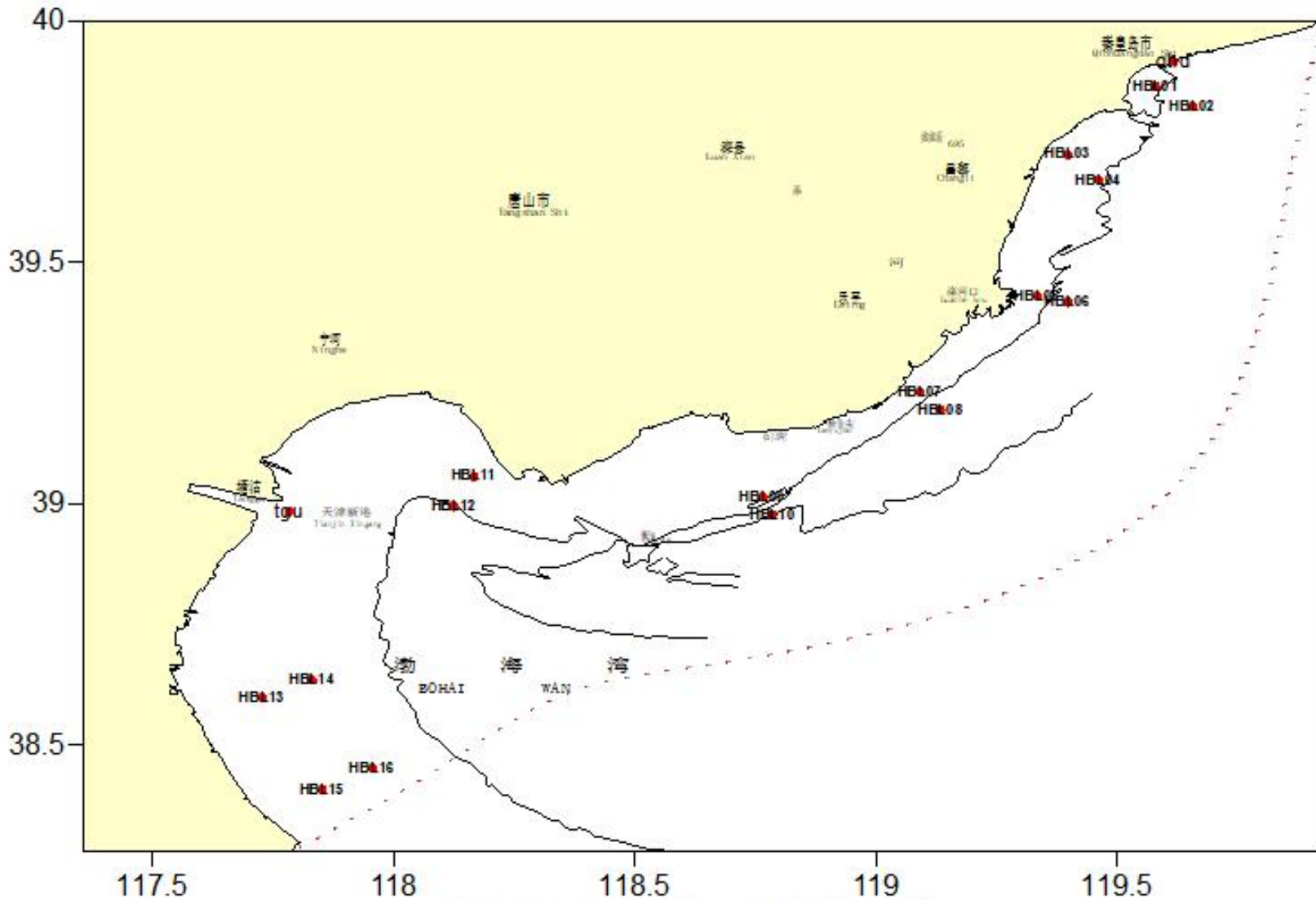


图 2.6-1 模型验证点位分布图

2.6.2 模型潮位计算结果比较图

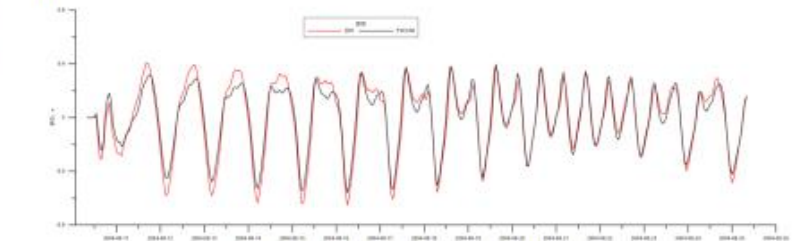


图 2.6-2 两模型在 qhd 站位模拟潮位比较图

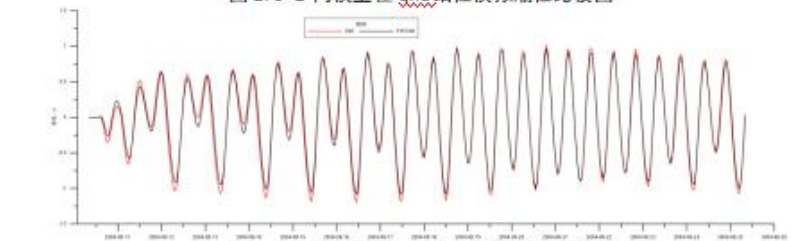


图 2.6-3 两模型在 tgu 站位模拟潮位比较图

2.6.3 计算结果与实测潮位比较图

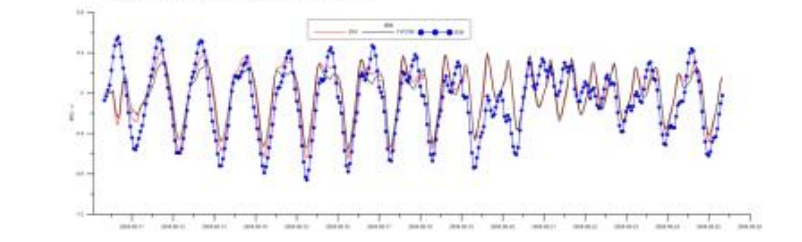


图 2.6-4 两模型在 qhd 站位模拟潮位与实测潮位比较图

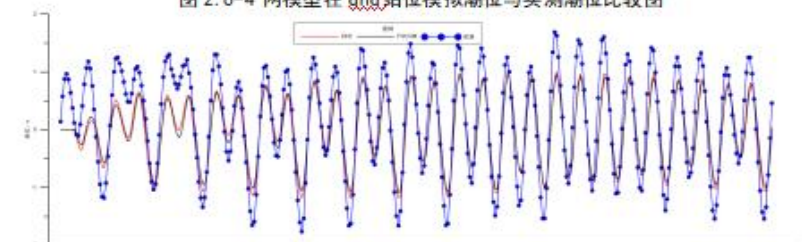


图 2.6-5 两模型在 tgu 站位模拟潮位与实测潮位比较图

comparing the results of our system and DHI Mike

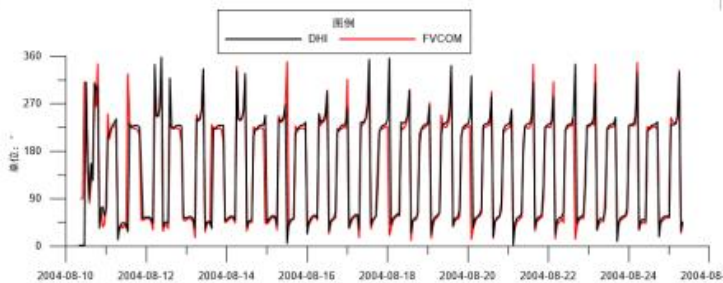


图 2.6-6 两模型在 BHL01 站位模拟流向比较图

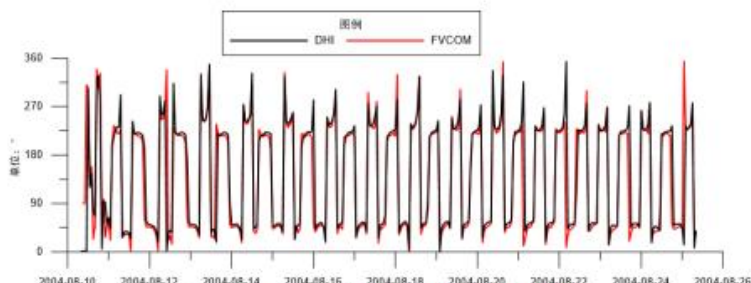


图 2.6-10 两模型在 BHL03 站位模拟流向比较图

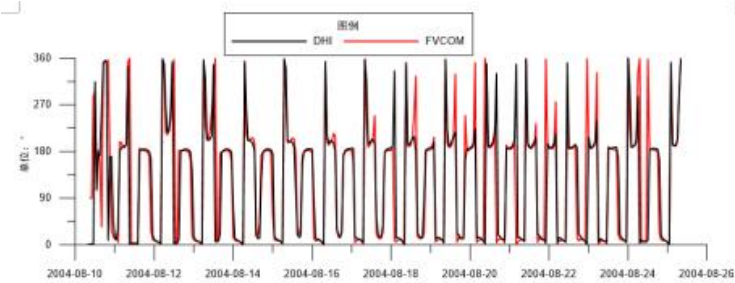


图 2.6-14 两模型在 BHL05 站位模拟流向比较图

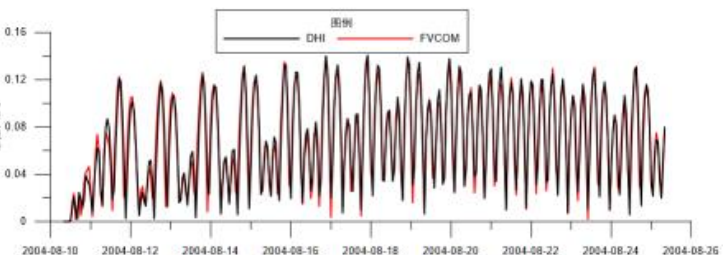


图 2.6-7 两模型在 BHL01 站位模拟流速比较图

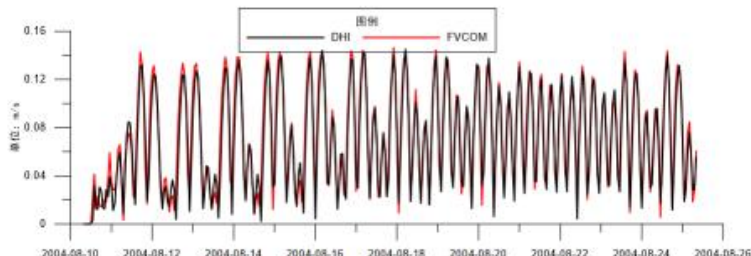


图 2.6-11 两模型在 BHL03 站位模拟流速比较图

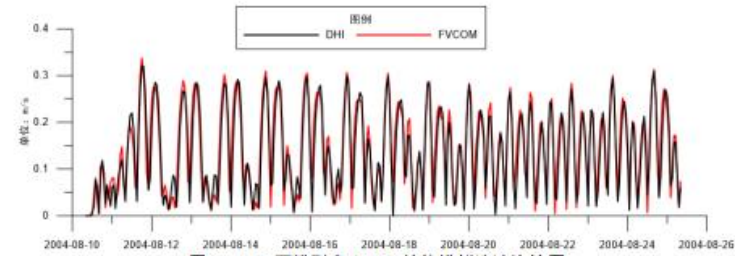


图 2.6-15 两模型在 BHL05 站位模拟流速比较图

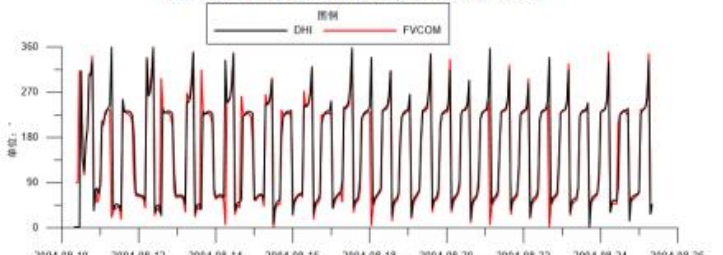


图 2.6-8 两模型在 BHL02 站位模拟流向比较图

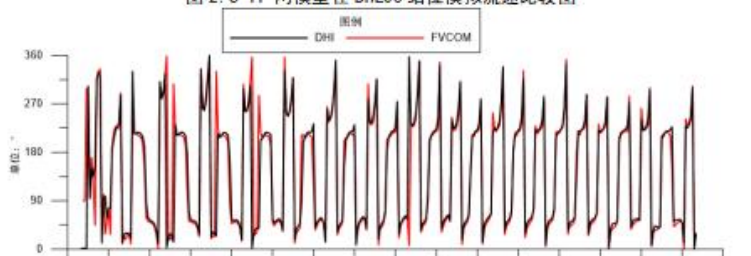


图 2.6-12 两模型在 BHL04 站位模拟流向比较图

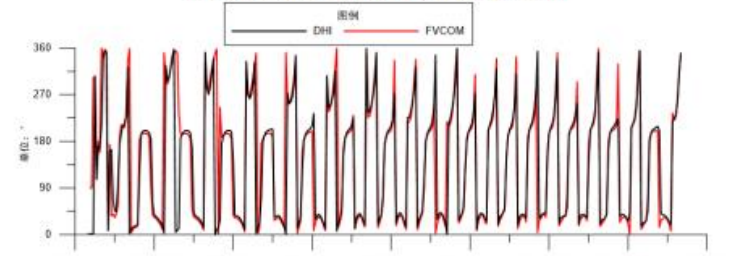


图 2.6-16 两模型在 BHL06 站位模拟流向比较图

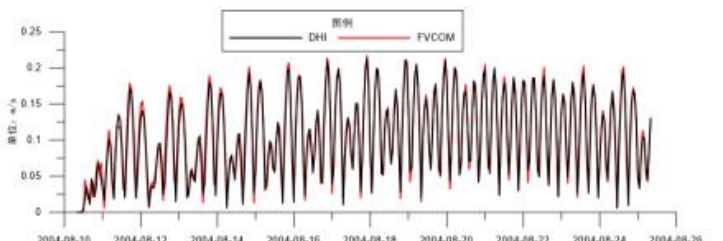


图 2.6-9 两模型在 BHL02 站位模拟流速比较图

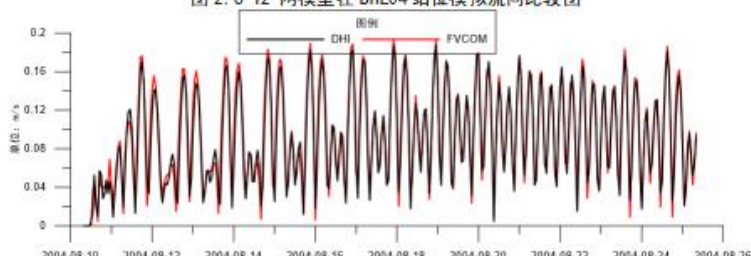


图 2.6-13 两模型在 BHL04 站位模拟流速比较图

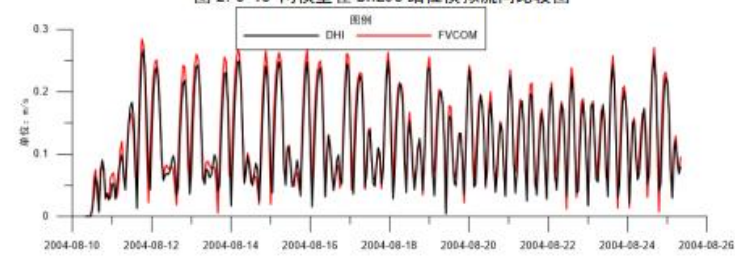


图 2.6-17 两模型在 BHL06 站位模拟流速比较图



Innovation and Highlights

1) **4 Models**, hydrodynamic numerical simulation, pollutant diffusion simulation and other businesses.

2) **Easy to use**, such as tidal forecasting, hydrodynamic simulation, and pollutant prediction without the need for in-depth professional knowledge.



Clicks to Build Ocean Models



Part **3**

Show some results
of our work

Clicks to Build Ocean Models



Impact of tidally induced residual circulations on chemical oxygen demand (COD) distribution in Laizhou Bay, China

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ABSTRACT

To understand the impact of hydrodynamics on pollutant transport in Laizhou Bay, China, we conducted numerical simulations using Mike 21. The model was calibrated with good agreements to field monitoring data at various monitoring stations. The simulation results show a clockwise and an anti-clockwise tidally-induced residual circulation in the western and eastern bay, respectively. Historical COD monitoring data also indicate two rings of high COD concentration in the same regions of the bay. This suggests that the hydrodynamics of tidal and residual currents is the main cause of the ring-shaped high COD concentration field in the bay. Pollutant inputs from inland rivers are also important for the COD distribution, making the near-shore side of the COD ring higher than the offshore side. Regions with higher retention time in the bay are usually associated with higher COD concentrations. This study is useful in understanding the mechanism of pollutant spatial distribution and subsequent pollution control in a sea bay.

1. Introduction

Sea bays, the buffer zones between inland and ocean aquatic environments, have important economic, social, environmental and ecological functions. In developing countries such as China, sea bays receive more and more industrial and urban pollutants from inland rivers as a result of rapid urbanization, industrialization and population growth in the catchment areas. These pollutants cause numerous issues in the receiving sea bays, including deterioration of water quality, contamination of sediments, destruction of ecological functions, decrease of piscatorial productions, and eutrophication (Wei et al., 2001; Wang et al., 2014; Yu et al., 2017). In particular, eutrophication in sea bays causes algal blooms, which induce hypoxia or anoxia in the water when algae die, killing fish or benthic organisms; and the algal toxins also bio-accumulate in the food chain to humans (Allahdadi et al., 2017).

Pollution level in a sea bay is not only affected by the inland pollutant loadings from local rivers but also by the hydrodynamics in the bay. Hydrodynamics directly determine the spatial distributions of pollutants, fish eggs, zooplankton and phytoplankton in the bay via the

transport and dispersion processes (Wang and Wang, 2007). Two types of currents are important in a sea bay, tidal currents and tidally-induced residual currents. The former plays an important role in short-term transport and dispersion of pollutants, while the latter controls the long-term processes with time scales from weeks to seasons.

To assess the pollution level in a sea bay, field measurement of pollutant concentrations is a common way (Tian et al., 2016). However, this method is time consuming, labour intensive and costly, and the measurement can only reflect the pollution level at the sampling locations and time. Numerical simulation is another important way of assessing pollution level in a sea bay given its typical large area. The foundation of any numerical simulation of water quality is hydrodynamic simulation. Numerous hydrodynamic models/software have been developed for oceanic studies, e.g., the Princeton Ocean Model - POM (Wei et al., 2015), the Finite Volume Coastal Ocean Model - FVCOM (Bao et al., 2015; Rowe et al., 2015), Estuarine, Coastal Ocean Model with Sediment Transport - ECOMSED (Li et al., 2015), Delft3D (Los et al., 2014), and MIKE products by DHI (Bolaños et al., 2014). To further analyze the output of a hydrodynamic model, Lagrangian particle tracking is a powerful method (Hufnagl et al., 2017; Van Sebille

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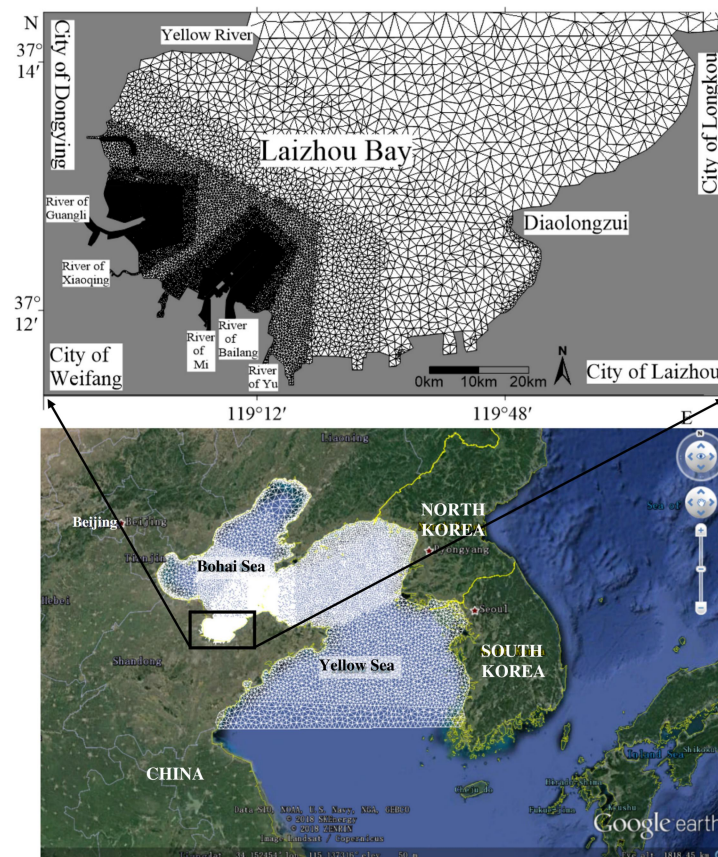


Fig. 1. Modeling domain and meshes in this study.

et al., 2018). This techniques has been used widely in tracking water masses (Safak et al., 2015; Sun et al., 2017), pollutants (Patgaonkar et al., 2012), fish eggs and larvae (Simons et al., 2013; Tanner et al., 2017), phytoplankton cells (Paterson et al., 2017), oil spill (Socolofsky et al., 2015; Main et al., 2017), micro- and meso-plastics (Lebreton et al., 2012; Iwasaki et al., 2017), giant jellyfish (Wei et al., 2015) and sediments (Aretxabaleta et al., 2014; Brown et al., 2015).

Many numerical studies have been conducted in sea bays. Allahdadi et al. (2017) used the DHI Mike 3 Flow Model - FM to evaluate the effects of wind, river and outer-shelf phenomena on circulation dynamics of the Atchafalaya Bay and shelf, United States. Safak et al.

(2015) used the FVCOM to estimate the tidally exchanged volume and associated repletion footprint in a system of shallow coastal bays. Havens et al. (2010) simulated the transport and dispersion of a toxic dinoflagellate bloom based on the circulation model adapted from the Princeton Ocean Model (POM) for the Tampa Bay, Florida. These studies showed that tidally-induced residual circulation in a bay is essential for the transport of water parcels and associated dissolved/particulate matters, affecting the water quality in the bay. The present study focuses on Laizhou Bay, one of the largest bays in Bohai Sea, China (Fig. 1).

Laizhou Bay is surrounded by the cities of Dongying, Weifang,

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Laizhou and Longkou. A large portion of the bay is used by oceanic facilities such as harbors, industrial hubs and seafood farming, resulting in large amounts of domestic and industrial effluents with various pollutants discharged into the bay (Liu et al., 2017). In 2013, more than one-fourth of Laizhou Bay failed to meet the Grade IV China National Sea Water Quality Standard (Jiang et al., 2017). Eutrophication has also been a social-economic concern in the bay. Numerous studies have been conducted in Laizhou Bay: spatial variation of microbial communities in sediments (Yu et al., 2017); distributions of heavy metals and dissolved organic matters in the water and sediments (Liu et al., 2017; Jiang et al., 2017; Xu et al., 2017); benthic habitat quality assessment (Luo et al., 2017); metal pollution in shrimp *Crangon affinis* (Xu et al., 2016); and spatial-temporal characteristics of the water circulation and sediment transport (Wei et al., 2001; Hainbucher et al., 2004; Wei et al., 2004; Zhou et al., 2017; Zhang et al., 2018). However, a systematic study is missing on hydrodynamic impact to pollutant spatial distribution in Laizhou Bay. Moreover, long-term pollutant transport processes in a sea bay have been less reported with time scales of over months.

In this study, we conducted numerical simulation of hydrodynamics for Laizhou Bay. The model was first calibrated with good agreement to the field data collected at various tidal synchronous monitoring stations in the bay. The hydrodynamics was then used to understand the distribution of historically measured concentration of chemical oxygen demand (COD) in the bay. The tidally induced pathways of Lagrangian particles were calculated, discussed and linked to the COD concentration. This study aims to improve the understanding on the mechanism of spatial distribution of pollutants in a sea bay, which is useful for the subsequent pollution control and mitigation measures.

2. Numerical model and monitoring data

2.1. Numerical model

Mike 21 Flow Model FM was used to build the hydrodynamic model in this study. Mike 21 FM, with a logical and user-friendly interface, has been widely used for simulating tidal currents and particle tracking (Jakacki et al., 2017; Joshi et al., 2017; Wang et al., 2017). Flexible Triangle Mesh Approach (www.mikepoweredbydhi.com) was used for spatial discretization of the computational domain (Fig. 1). The advantage of this approach is that meshes can be densified in the areas of interests. For instance, denser meshes near the coastline make the boundary smoother, which reduces the negative impact of jagged meshes to the modeling results.

The hydrodynamic model included boundary conditions, wind friction at the sea water surface, friction at the sea bed, Coriolis force, and water flow rates of point sources of pollution. The model used standard k-ε turbulence model and tide driven mode. The open boundary was set to be between the City of Rizhao of China and the City of Busan of South Korea (Fig. 1). The water level at the open boundary was set by using tidal harmonic constants at the Rizhao Port and other locations. These constants were analyzed from major tidal constituents (M_2 , S_2 , O_1 , K_1) based on long-term monitoring data of tidal elevation. Co-tidal chart in Marine Hydrological Atlas of Yellow Sea and Bohai Sea was also used in the model. The modeling domain was $117^{\circ}12' \text{E}$ and $35^{\circ}41' \text{N}$, with a distance of 750 km and 650 km in the east-west and south-north direction, respectively, and a total area of about $360,000 \text{ km}^2$. The mesh size in the computational domain generally increased from about 100 m nearshore to 10–20 km in the open sea (Fig. 1). The mesh size was determined based on computational resolution requirements in different zones of the modeling domain, sensitivity analysis of modeling results, and computing power restriction.

2.2. Tidally-induced Eulerian mean circulation

The non-linear effect of tides generates residual current, which may

further generate tidally induced Eulerian mean circulation. Eulerian residual currents can be simply defined as the averaged velocities in an Eulerian flow field. It is calculated by decomposition of the velocity in x- and y-axis in the Cartesian coordinate system:

$$\begin{aligned} U_E &= \frac{1}{N} \sum_{i=1}^N u_i \\ V_E &= \frac{1}{N} \sum_{i=1}^N v_i \end{aligned} \quad (1)$$

in which, U_E and V_E are the Eulerian mean velocity in x- and y-axis, respectively; $N = nT/dt$, in which n is the number of computational periods, T is the tidal periodicity and dt is the computational time step; and u_i and v_i are the velocity at step i in x- and y-axis, respectively.

2.3. Lagrangian particle tracking model

In tide-dominant shallow sea areas, long-term transport of pollutants depends on the net displacement of water mass after many tidal periodicities, and Lagrangian method is the best way to describe this (Allahdadi et al., 2017). Particle tracking models numerically release virtual particles and follow their trajectories within a given computational time to reflect the flow field and mass transport in the study area.

The particle tracking technique on transport and dispersion of particles follows the Langevin Equation. According to Einstein's explanation of observed Brownian motion in the first decade of last century, Langevin and others formulated the dynamics of such motions in stochastic differential equations. The resulting equation can be written as (DHI, 2012):

$$dX_t = a(t, X_t)dt + b(t, X_t)\xi_t dt \quad (2)$$

where a is the drift term, b is the diffusion term, and ξ_t is the random number.

To simulate trajectory of the Euler approximation (Y) for a given time discretization, we simply started from the initial value $Y_0 = X_0$ and proceeded recursively to generate the next value:

$$Y_{n+1} = Y_n + a(t_n, Y_n)\Delta t_n + b(t_n, Y_n)\Delta W_n \quad (3)$$

where $n = 1, 2, 3, \dots$ according to the Euler scheme with the drift a and the diffusion coefficient b . Herein $\Delta W_n = W_t - W_{t_n} \sim N(0, \sigma^2 = \Delta t_n)$ is the normal distributed Gaussian increment of the Wiener process W , where W is a continuous time Gaussian stochastic process with independent increment over the subinterval $\tau_n \leq t \leq \tau_{n+1}$. Since the diffusion coefficient b may make the trajectory uncertain for long-term transport, horizontal and vertical dispersions were assumed to be zero in this study and only the drift was taken into account. To understand the long-term pollutant transport in Laizhou Bay, this study used virtual particles released at 20 km away from each other in the bay (Fig. 2).

2.4. Water depth and COD data

The data of water depth used in this study were based on the digitized marine chart published by the Navigation Guarantee Department of Chinese Navy Headquarters and the digital marine chart of DHI C-MAP. The coastline in the study region reflects the mean high water spring tide. It was first extracted from Google Earth Images. The coastline was then refined with N. 11840 Marine Chart published in October 2005 (1st Edition) by Navigation Guarantee Department of Chinese Navy Headquarters.

The COD data used in this study were monitored in 2008 and 2012 by North China Sea Environmental Monitoring Center, North China Sea Marine Forecasting Center, and the First Institute of Oceanography of State Oceanic Administration, China. Detailed information of these monitoring programs is provided in Table 1, and the measurement sites and concentrations are shown in Fig. 3.

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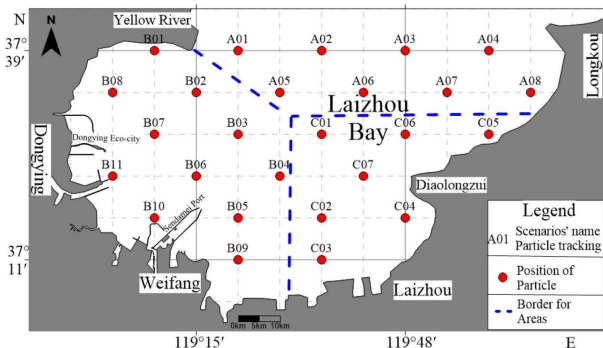


Fig. 2. Initial release locations of particles tracked in the Lagrangian model.

3. Results

3.1. Model calibration

The model was calibrated by using the data at six tidal synchronous monitoring stations (see Fig. 4 for their locations) monitored by North China Sea Marine Forecasting Center and State Oceanic Administration of China. Comparisons between the modeling results and field data are presented in Fig. 5, including both magnitudes and directions of tidal currents at 0.5 m below the water surface.

The comparison results in Fig. 5 show that the simulation generally agrees well with the measurement data for both velocity magnitudes and directions. There are some discrepancies in velocity directions at the initial stage of the simulation. However, with the continuance of the simulation, such discrepancies significantly decrease to a satisfactory level. This suggests that the discrepancies might be caused by the model instability at the beginning of the simulation. Overall, the simulation result is able to reasonably represent the tidal current velocities. Therefore, the model is deemed to satisfactorily reflect the tidal flow field in Laizhou Bay.

3.2. Tidal flow fields

The simulated depth-averaged tidal flow fields are shown in Fig. 6. The simulation for flood tide is in Fig. 6a. The areas to the southeast of the Yellow River Mouth (Old Yellow River Mouth after 1997, to be more precise; same definition below) and to the northwest of Diaolongzui have velocities of more than 1 m/s. The area to the west of Sendamei Port has velocities of about 0.9 m/s, which generally decreases landward. The sea area to the east of the Yellow River Mouth generally has a south flow direction, while it is generally north in the

area to the south of the river mouth. To the east of the City of Dongying, the current flows west at about 0.4 m/s. To the south of Diaolongzui, the current is about 0.2 m/s flowing southeast; while to the north of Diaolongzui, it is about 0.4 m/s flowing southwest. The present modeling results generally agree with Wang et al. (2017) who conducted hydrodynamic modeling using DHI MIKE 3 FM for the region near the Yellow River Mouth.

Fig. 6b shows the flow field for an ebb tide. The velocities are larger in the following areas: to southeast of the Yellow River Mouth, to northwest of Diaolongzui and to the west of Sendamei Port, with velocities at or above 0.9 m/s. In the area eastern of the City of Dongying, the current flows approximately east at about 0.3 m/s. Close to Sendamei Port, the current flows northeast with a velocity of about 0.1–0.3 m/s. Similarly, as in the case of flood tide shown in Fig. 6a, the current decreases from the sea to the coastline. To the southwest and north of Diaolongzui, the velocities are about 0.2 m/s.

3.3. Tidally induced residual current field

The simulated tidally-induced Eulerian residual current field in Laizhou Bay is shown in Fig. 7. Several circulations of residual current can be clearly seen in Fig. 7. There is a clockwise circulation to the south of the Yellow River Mouth, with larger residual velocities near the shore (about 0.2 m/s) than those offshore. An anti-clockwise circulation exists to the west of Diaolongzui, with residual velocities of over 0.15 m/s. A clockwise circulation also exists to the north of Diaolongzui, with residual velocities of less than 0.05 m/s. To the northeast of Sendamei Port, a clockwise circulation exists. Generally, the residual current field is complex in Laizhou Bay.

Wan et al. (2004) conducted numerical simulation of summer tidally-induced, wind-driven and thermohaline currents in Bohai Sea (see

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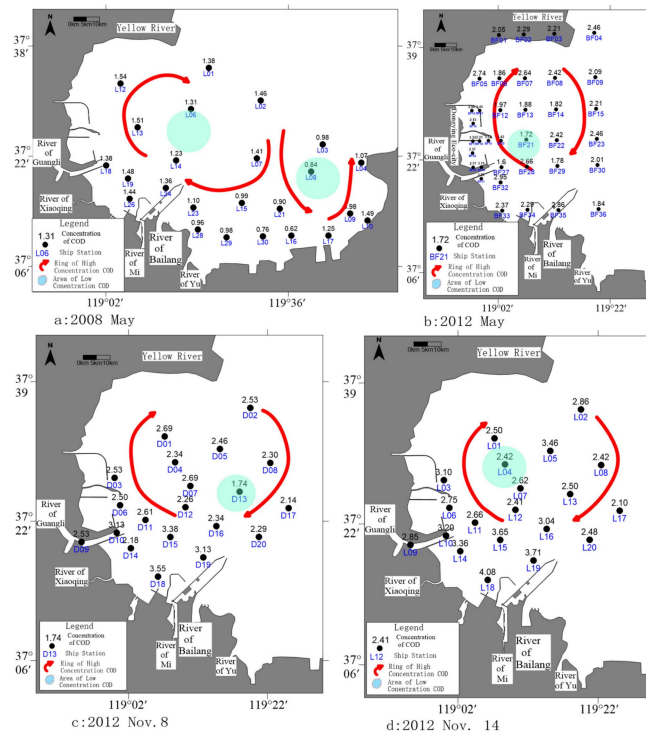


Fig. 3. COD measurement sites and concentrations (in mg/L) in 2008 and 2012. The directions of the rings are based on the simulation results of tidally-induced residual current field.

Fig. 1 for the location of Bohai Sea). Their results showed that tidally-induced residual current in Laizhou Bay can be divided into two branches: one branch flows out of the bay from the eastern Laizhou Bay; and the other branch generates a clockwise circulation to the south of the Yellow River Mouth. Their results generally agree with the computational results of this study, although the two studies used different oceanic models, boundary conditions, mesh sizes and time steps. In this study, the mesh size and time step are smaller and therefore the tidally-induced residual current field is believed to be more accurate. Similarly, the results of Qiao et al. (2016) in Bohai Sea and Yellow Sea (see Fig. 1 for the location of Yellow Sea) overall agree with the current study despite some difference for the reasons listed above.

3.4. Lagrangian particle tracking

To better analyze the Lagrangian trajectory of virtual particles released in Laizhou Bay, we divided the bay into three regions (Fig. 2): the northern region with the corresponding modeling scenarios of A01–A08; the western region with the modeling scenarios of B01–B11; and the eastern region with the modeling scenarios of C01–C07. Similar particle tracking technique was used in the Atchafalaya Bay in the United States with DHI MIKE 3 Flow Model (Allahdadi et al., 2017). The modeling results for the three regions are presented in Fig. 8a, b and c, respectively.

As shown in Fig. 8a, the pathway of particles in the northern bay is relatively simple: they generally move northward from the bay to Bohai

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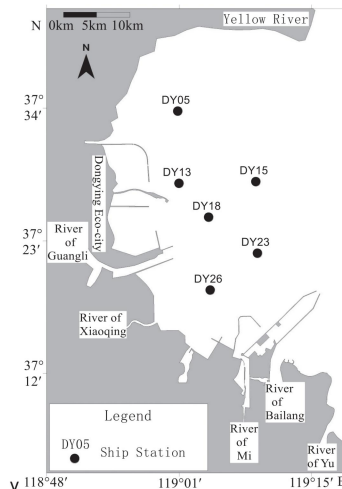


Fig. 4. Tidal synchronous monitoring stations in Laizhou Bay in 2011 for model calibration.

Sea. To be more specific, in scenarios A01, A04, A05, A07 and A08, they move eastward first and then turn northward to Bohai Sea. However, in the western Laizhou Bay as presented in Fig. 8b, the pathway is significantly different. The results of scenarios B01–B11 generally show a clockwise circulation in the region to the west of the City of Laizhou and to the south of the Yellow River. In scenario B02, the particle's pathway shows a circle shape in the western bay after about 90 days from release. Then it turns north from Laizhou bay to Bohai Sea after about 100 days, which is similar to scenarios A01–A06. Similar circle-shape clockwise circulations can be observed in scenario B04 and B07. The results in other scenarios show part of the circle-shape circulation, e.g., in scenario B03, B05, B09 and B11, the particle's movement is controlled by the southern part of the clockwise circulation and their net transport is from east to west. In scenario B01 and B08, the particles move east first and then turn north to the Bohai Sea after about 20 and 30 days, respectively. Afterwards, the particles show similar characteristics of northward movement as in scenarios A01–A06. In scenario B06, particle is transported northward to the Yellow River after about 60 days and then it turns around from the Yellow River to Diaolongzui after about 90 days, and finally it is detained to the west of Diaolongzui.

In the eastern Laizhou Bay, overall, there are three types of particle movement (Fig. 8c). The first one is the particles move counter-clockwise to the west of Diaolongzui in scenario C01, within 30 days in scenario C02, and within 90 days in scenario C03. The second type is that the particles are detained to the west of Diaolongzui in scenario C01, C04 and C07. The third type is the particles move clockwise to the north of Diaolongzui in scenarios C05 and C06. The result of scenario C02

shows how a particle to west of Diaolongzui moves out of Laizhou Bay: it moves toward and along the shore first and then moves northward out of the bay. Interestingly, in scenario C02, the particle movement shows a clockwise circulation in Day 50–90 to the north of Diaolongzui.

Fig. 9 shows the contours of net and total travel distances of all particles within 240 days after release. The net distance shows a particle's net transport, while the total distance is the integration of the distance of every time step of the particle's movement. The results show that there are two regions with the net distance of more than 70 km: at the mouth of Laizhou Bay (A03 and A06 in Fig. 8); and in the western Laizhou Bay (B02, B07 and B08). This suggests that the particles in these regions move rapidly, which can significantly dilute pollutants with ambient seawater. However, in the region to the west of Diaolongzui and near the shore of the cities of Weifang and Dongying, the net transport distance is less than 10 km (B10, B11 and C07). This indicates that the particles and pollutants are prone to accumulate in these regions with higher concentrations. The distribution of total travel distance is shown in Fig. 9b. There are two regions with less than 1000 km near the cities of Dongying (B11) and Weifang (B05 and B09). Two regions have the total transport distance of less than 3000 km: to the north of Diaolongzui (A07 and C06) and between cities of Dongying and Weifang (C02, C03 and B10).

3.5. COD concentration field

Fig. 3a shows the COD concentration field in May 2008, ranging 0.6–1.5 mg/L. To the south of the Yellow River Mouth, there is a clear ring of COD concentration field, with L06 (1.3 mg/L) and L14 (1.2 mg/L).

Table 1 Summary of COD monitoring in 2008 and 2012.			
Year	Date	No. of monitoring sites	Monitoring agency
2008	May 12–June 1	24	North China Sea Environmental Monitoring Center, State Oceanic Administration, China
	May 23–May 25	36	
2012	Nov 8	20	North China Sea Marine Forecasting Center, State Oceanic Administration, China The First Institute of Oceanography, State Oceanic Administration, China
	Nov 14	20	

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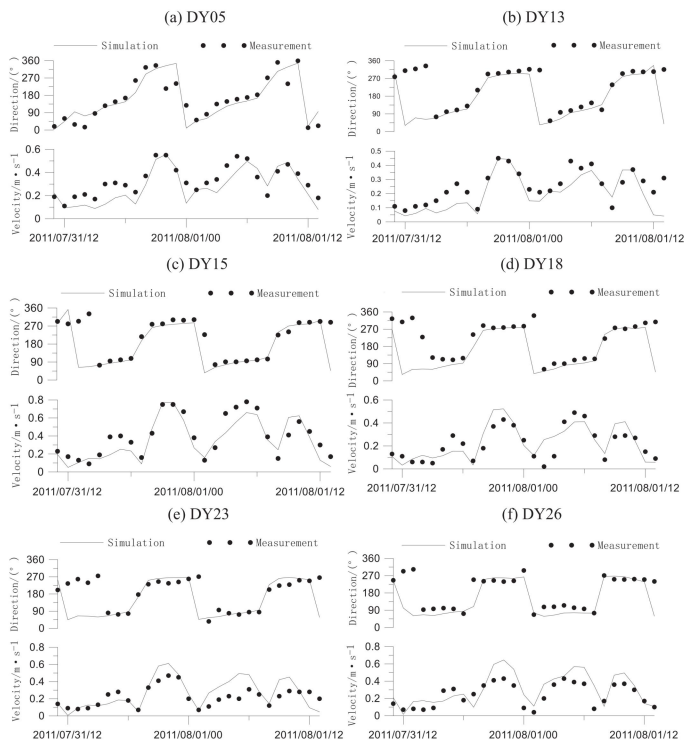


Fig. 5. Comparisons of the measured and simulated results of tidal velocity direction and magnitude at various tidal synchronous monitoring stations for 24 h.

L) as its center, surrounded by a ring of higher COD concentrations (1.24–1.13–1.01–1.02–1.07–1.24) of 1.4–1.5 mg/L. The area to the west of Diaolongzui appears to have another ring of COD concentration field: with L08 (0.8 mg/L) as its center and a ring of higher COD concentrations (1.07–1.21–1.17–1.09–1.04–1.03–1.07) of 0.9–1.4 mg/L.

Fig. 3b–d show the COD concentration field in May and November 2012, in which the measurements were only conducted in the western Laizhou Bay. As shown in Fig. 3b, with more measurement points in May 2012 compared to 2008, the COD ring can be more clearly seen: low COD area (BF21 and BF13; 1.7–1.9 mg/L) is in the center, surrounded by a ring of high COD points (2.0–3.2 mg/L). The COD ring has higher concentration in the west/near-shore side than the east/off-shore side, which agrees with Fig. 3a. Overall, the COD concentration field in May 2012 agrees with those in May 2008.

Fig. 3c–d show the COD concentration fields measured on Nov 8 and

14, 2012. Similar ring-type COD concentrations can be observed in the western Laizhou Bay as in May 2008 and May 2012. In Fig. 3c, the low concentration area is near D13 (1.7 mg/L), surrounded by a ring of high COD concentrations (2.1–3.4 mg/L). Again, the ring has higher concentrations in the west side than the east side. Similar conclusions can be made from Fig. 3d, with the low COD of 2.4 mg/L (near L04) and the high COD ring of 2.5–3.7 mg/L. In addition, all Fig. 3a–d show that the COD concentration is generally higher to the west of Sendamei Port than that to the east.

4. Discussion: COD distribution versus hydrodynamics

The monitored COD concentration fields in May 2008, May 2012, and Nov 2012 have a high degree of similarity to the tidally-induced Eulerian residual current field and agree with the Lagrangian particle

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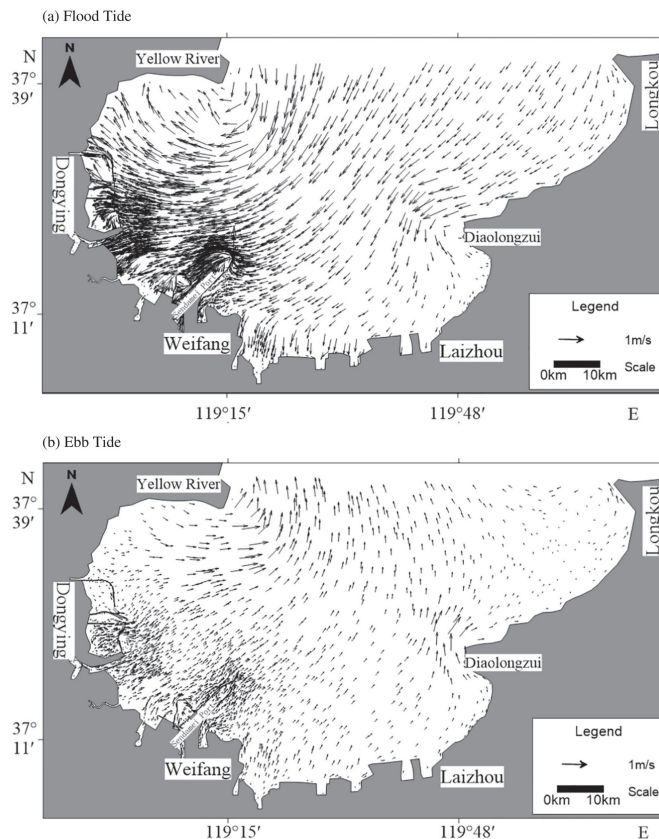


Fig. 6. Modeled current fields during (a) flood tide and (b) ebb tide in Laizhou Bay.

tracking results. This suggests that hydrodynamics is the primary mechanism for the spatial distribution of COD concentration in Laizhou Bay.

4.1. High COD concentration ring to the south of the Yellow River mouth

The COD monitoring results in 2008 and 2012 clearly show a ring of high COD concentration located in the area to the south of the Yellow River Mouth and to north of Sendamei Port. This agrees well with the

clockwise circulation of Eulerian residual current field in that region as shown in Fig. 7a. The particle tracking results at B02–04 and B06–07 in Fig. 8b also suggest the clockwise flow circulation. The center location of the COD rings shifts slightly in Fig. 3a–d, which is likely caused by the limited number of monitoring points for COD and the different tidal conditions at the time of monitoring. Based on Fig. 7a, the high COD concentration in the west/near-shore side of the ring is believed to be caused by the transport of inland effluents from the local rivers (e.g., Xiaqing River and Guangli River; Fig. 3) in the cities of Weifang and

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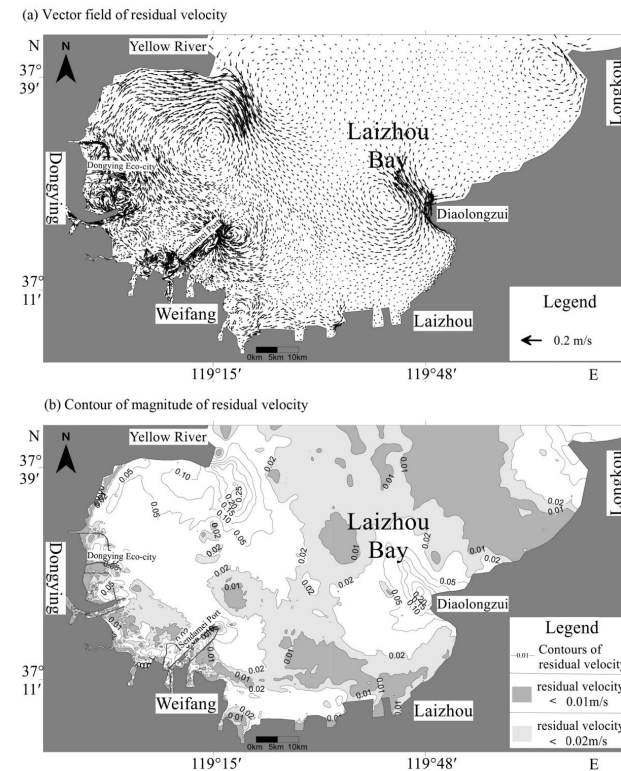


Fig. 7. Modeled tidally-induced residual current field in Laizhou Bay: (a) vector field and (b) contour of velocity magnitude.

Dongying. While in the east/off-shore side of the ring, the high COD is speculated to be caused by the transport of pollutants from the Yellow River (based on the high COD concentration near the River Mouth as shown in Fig. 3b–d) and together by the pollutants carried from the cities of Weifang and Dongying. The higher COD concentration in the near-shore side of the ring than the off-shore side is possibly resulted from that COD gets diluted and decayed when the water travels from the near-shore to off-shore side.

4.2. High COD concentration ring to the west of Diaolongzui

The high COD concentration ring to the west of Diaolongzui in Fig. 3a is also in accordance with the anti-clockwise circulation of Eulerian residual current field in that region as presented in Fig. 7a. The anti-clockwise circulation can be also observed from the particle tracking results of C1 and C2 in Fig. 8c. The monitoring results in 1984 and 1989 (not shown in this paper) also suggest an area of high COD concentration to the west (1984) or northwest (1989) of Diaolongzui,

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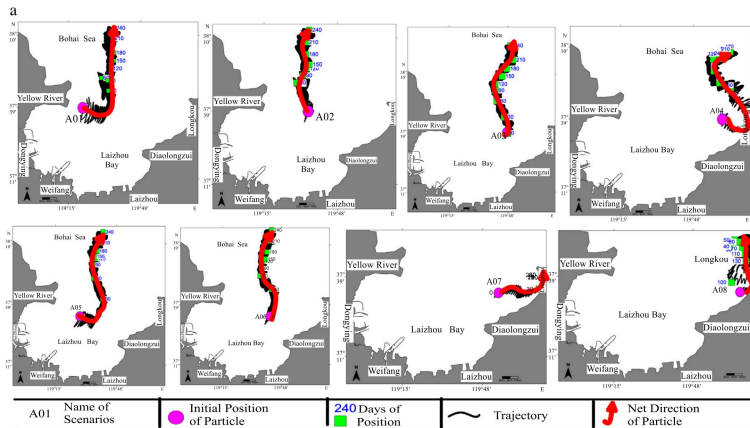


Fig. 8. a. Modeled trajectories of virtual particles released at A01 to A08, which present an outgoing type in the mouth of Laizhou Bay. b. Modeled trajectories of virtual particles released at B01 to B11, which show clockwise circulation in western Laizhou Bay. c. Modeled trajectories of virtual particles released at C01 to C07, which show a detained type to the west of Diaolongzui.

although the measurement points in 1984 and 1989 were too sparse to suggest a ring shape of high COD concentration. It is possible that the high COD points in 1984 and 1989 were within the ring of high COD concentration.

There are no major rivers nor effluent discharges entering t near Diaolongzui, and therefore the high COD ring is caused by t hydrodynamics there. From the Lagrangian particle tracking res Fig. 8c, particles released at numerous locations such as C01, C

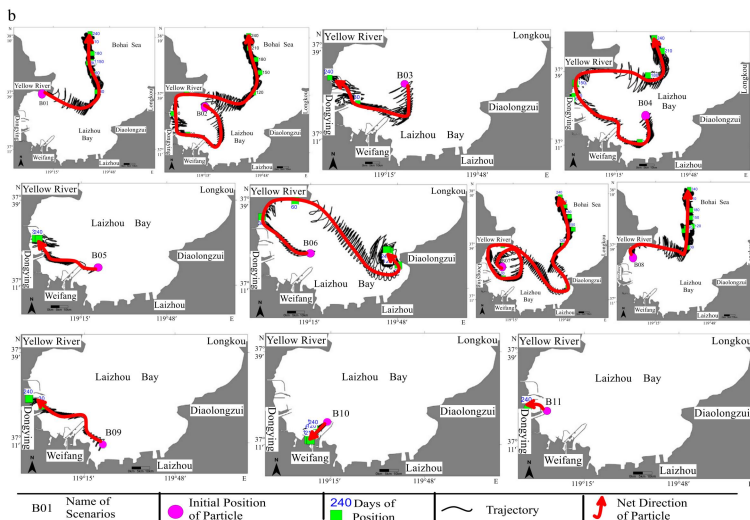


Fig. 8. (continued)

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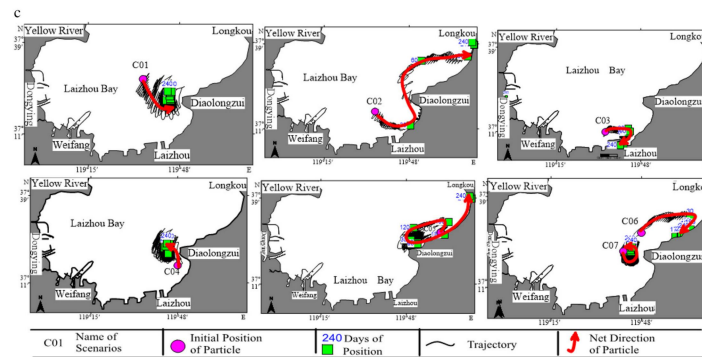


Fig. 8. (continued)

C07 will be trapped in the sea area to the west of Diaolongzui. This suggests that pollutants may accumulate in that area, which explain the high COD points in that area in 1984 and 1989 and the high COD ring in 2008. This also implies that it is not suitable to approve any effluent outfalls in that area as the hydrodynamics is not in favor of pollutant transport and mixing.

4.3. High COD concentration to the west of Sendamei Port

From the COD measurement results, the sea area to the west of Sendamei Port has an obviously higher COD concentration compared to its ambient areas: it reached 1.4–1.5 mg/L in May 2008, 2.3–2.4 mg/L in May 2012, and 3.55 mg/L and 4.08 mg/L on November 8 and 142,012. This might be caused by the small residual current (0.05 m/s) (Fig. 7b) and small net travel distance (Fig. 9a) near the port, suggesting the long retention time and low pollutant transport capacity in this area compared to other areas in the bay. This might be also related to the high COD effluent carried from the nearby Xiaogang River and Mi River into the bay (Fig. 3).

5. Conclusions

This paper presents a numerical study of tidal and tidally-induced residual currents in Laizhou Bay, Bohai Sea, China. The model was calibrated with field monitoring data from six in-situ tidal synchronous monitoring stations. The simulation results were used to understand the impact of hydrodynamics on the spatial distribution COD concentration field in the bay. Major conclusions are as follows.

- The simulation results on Eulerian tidally-induced residual current show a clockwise circulation in the sea area to the south of the Yellow River Mouth and an anti-clockwise circulation to the west of Diaolongzui in Laizhou Bay. The Lagrangian particle tracking results show similar circulations in these two areas.
- The COD concentration field measured in 2008 and 2012 overall agrees with the above hydrodynamic results. Particularly, the two rings of high COD concentration to the south of the Yellow River Mouth and to the west of Diaolongzui agree well with the two circulations of residual currents in these two regions. This suggests the important impact of hydrodynamics on pollutant transport in a sea bay.

- It appears that the inputs of inland pollutants from local rivers to the receiving bay can also change the COD concentration field in the bay. These inputs are believed to be the main reason for the higher COD in the near-shore side of the COD ring than the off-shore side of the ring in the area to the south of Yellow River Mouth.
- It is also found that local high COD regions such as to the west of Diaolongzui and to the west of Sendamei Port are associated with high retention time of pollutants and low net travel distance in the bay. This is because pollutants are more likely to accumulate under such conditions.

Generally, this paper demonstrates the importance of hydrodynamics on pollutant concentration field in a sea bay. The results will be useful in guiding numerous activities in a bay such as pollution control, fishery protection, understanding algal bloom generation mechanism and mitigation measures, and studying sediment transport. Future studies will be on the impacts of inland river pollutant loadings to the bay water quality and impacts of hydrodynamics on pollutant decay and fate in the bay.

Author contribution

Wanqing Chi: Conceptualization, Methodology, Software, Writing-Original draft preparation, Investigation **Xiaodong Zhang:** Funding acquisition, Writing - Review & Editing **Wenming Zhang:** Conceptualization, Methodology, Writing-Original draft preparation, Writing - Review & Editing **Xianwen Bao:** Funding acquisition, Writing - Review & Editing **Yanling Liu:** Writing - Review & Editing **Congbo Xiong:** Writing - Review & Editing **Jianqiang Liu:** Writing - Review & Editing **Yongqiang Zhang:** Writing - Review & Editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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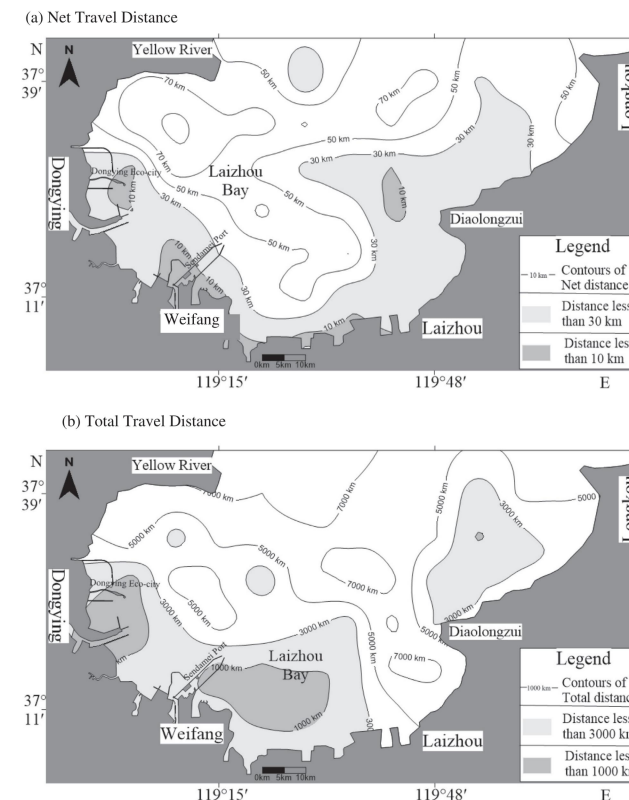


Fig. 9. The contours of (a) net and (b) total travel distances of the released particles during 240 days.

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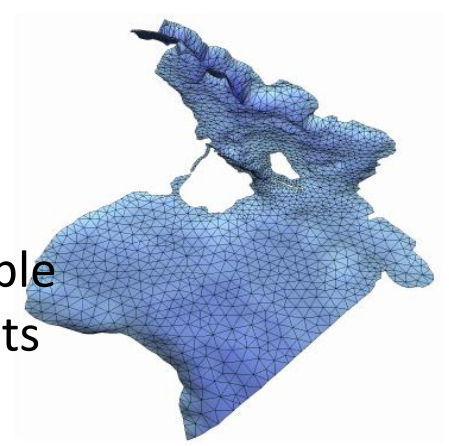




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- 3) NEMO (Nucleus for European Modelling of the Ocean)
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