SYMPOSIUM OP'24

Ocean Predict

In partnership with unesco Intergovernmental Oceanographic Commission

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

Operational Forecasting Systems for Maritime Emergency in NMEFC: an Integrated Decision Support for Maritime Emergency Response and Management

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CONTENT

01

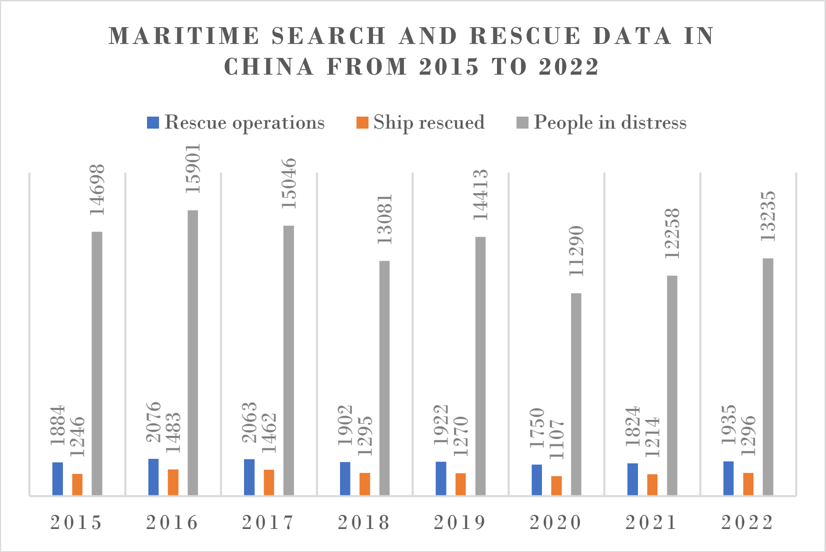
Background Introduction

Maritime hazards pose threats to the environment and human activities and proverty

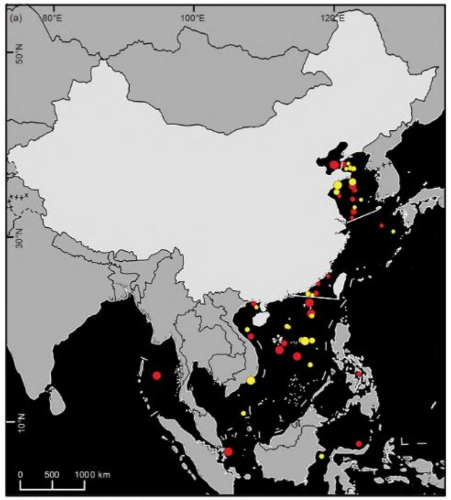
According to the statistics from the National Maritime Search and Rescue Center (NMSRC), in 2022 alone, the NMSRC organized and coordinated 1935 rescue operations, in which 1110 ships and 10834 people were saved[1].

57 oil spill incidents were detected by the HY-1C/D in the China seas from 2019-2021, the image area of spilled oils can be up to 1291.63 km^2[2].

There is an urgent need for using marine forecasting system to respond to emergencies!



"Bingo" shipwreck in 2013



Oil spill from the damaged "Symphony"

Non-emulsified oil spill (26 times)

Emulsified oil spill (31 times)

1.2 Development of maritime emergency forecasting systems in NMEFC

The development of maritime emergency forecasting system is a reflection of the revolution of marine environmental forecasting models.

1980s-2010s

Numerical models are developed for physical-biological forecasting on regioanl to global scales

Boost of physical models

Launch of the first generation of global-regional forecasting system constructed by NMEFC

2008-2015

Maritime emergency forecasting models began to develop

Preliminary research

2D/3D oil spill models
Ensemble forecast of oil spill (OSCAR, GNOME, OILMAP, NMEFC-OILMAP)
NMEFCSAR v1.0
SARMAP, OILMAP

2015-2022

Enrich characteristic coefficient database
Consider more complex physical and chemical processes

Technical improvement

- **Oil spill weathering model (v2.0)**
- **Oil spill for ice region**
- **Mobile source oil spill forecast**
- **Linear - leeway - semi-analytical model for SAR**
- **Unified maritime emergency forecasting platform**

2023-

Coupled with the new Mass Conservation Ocean Mod aCOM)

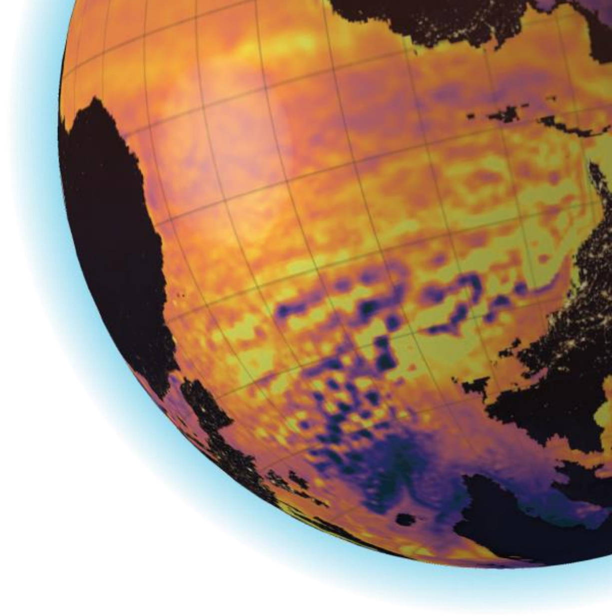
Explosive Growth

Maritime emergency forecasting system based on GPU

Computing power → More numerical cases, Higher resolution, More complex physical processs → Theoretical progress

The rapid development of GPU and other computing technologies is likely to bring a new round of model innovation

1.3 Requirements for the operational emergency forecasting



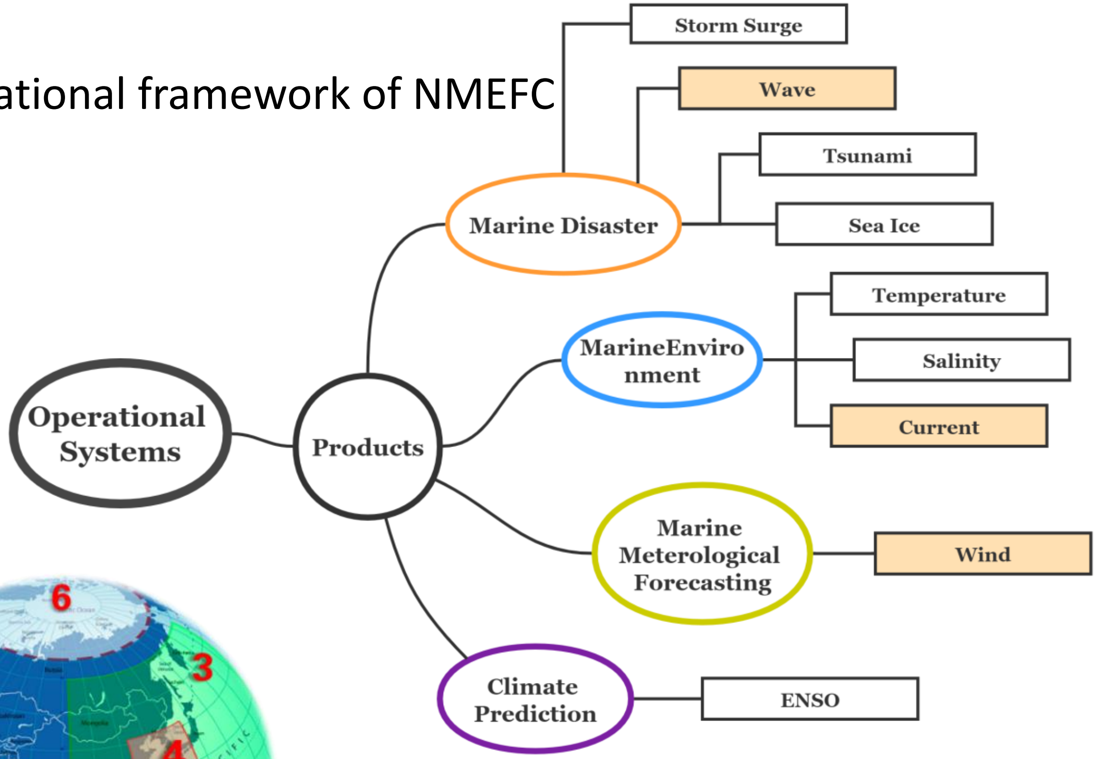
01 **High-efficient, stable, and easy to operate**

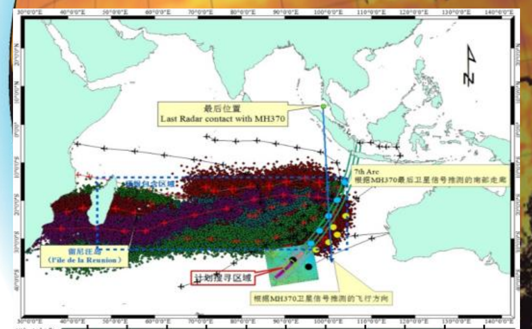
02 **Friendly to multi-source data**

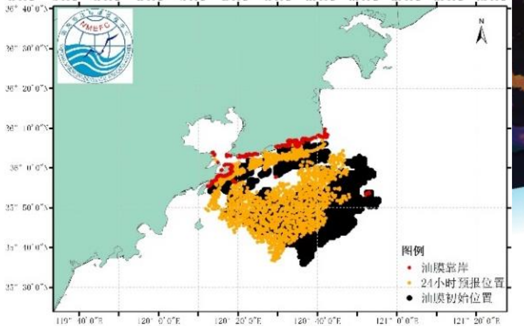
03 **A unified platform that ready to provide multifactor-forecast on various spatial scales**

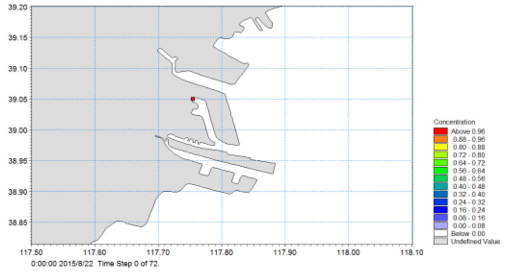
1.4 Operational marine forecasting products in NMEFC

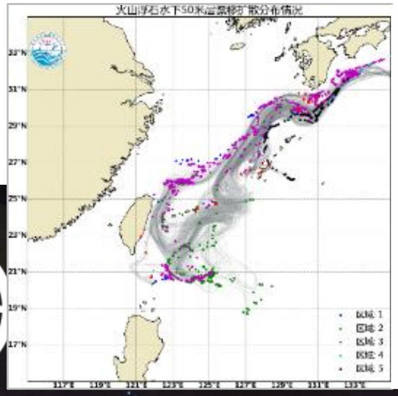
Operational framework of NMEFC

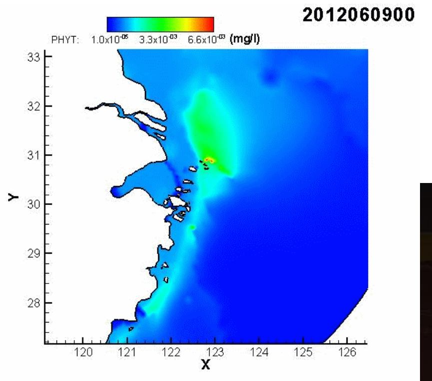












» **Global-Reginal oceanography forecasts**

1: Global Ocean (1/12°)

2 & 3: Northwest Pacific and Indian Ocean (1/20°)

4 & 5: Bo-Yellow-East China Sea and South China Sea (1/30°)

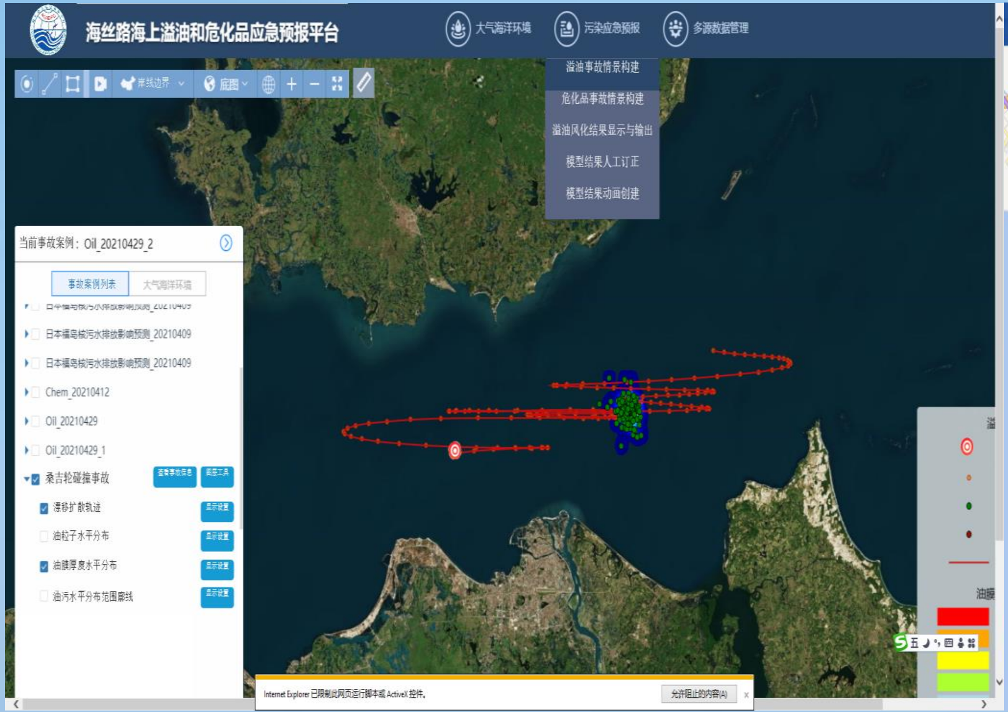
6: Polar region

» **Refined forecasts for coastal zone**

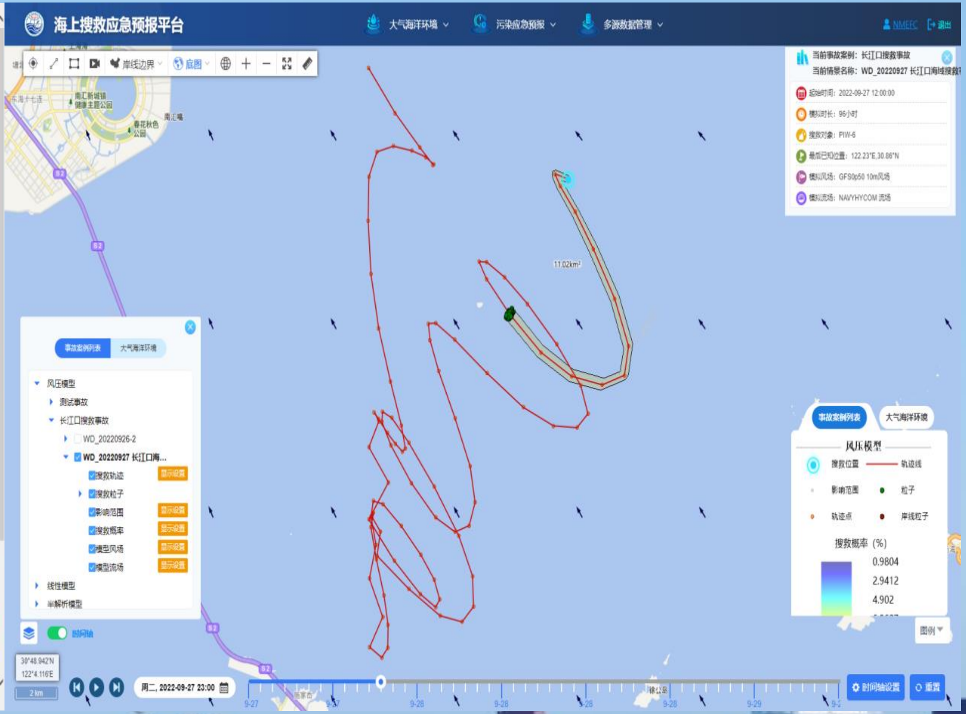
NMEFC 退出

Maritime Emergency Forecasting Platform

海上事故应急预报平台



Oil Spill and Hazardous Chemical Emergency Forecasting Platform

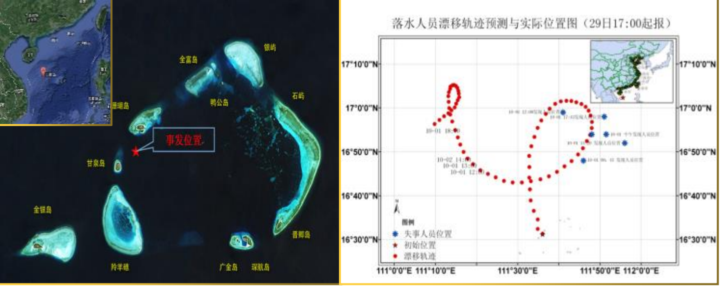


Search and Rescue Emergency Forecasting Platform

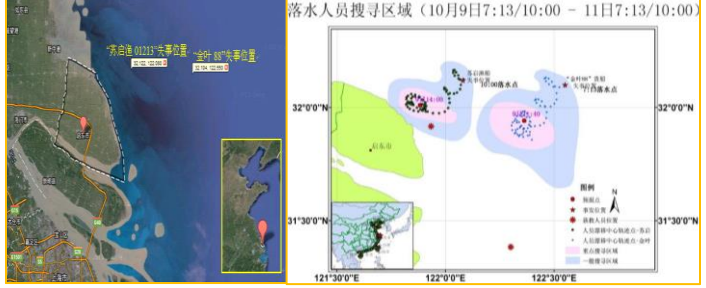
When a maritime accident occurs:

- Input the accident information on the human-computer interaction interface
- The system automatically calculate the drift trajectory of the accident target, the diffusion range of the oil spill, etc.
- The entire process can be calculated in a few minutes.

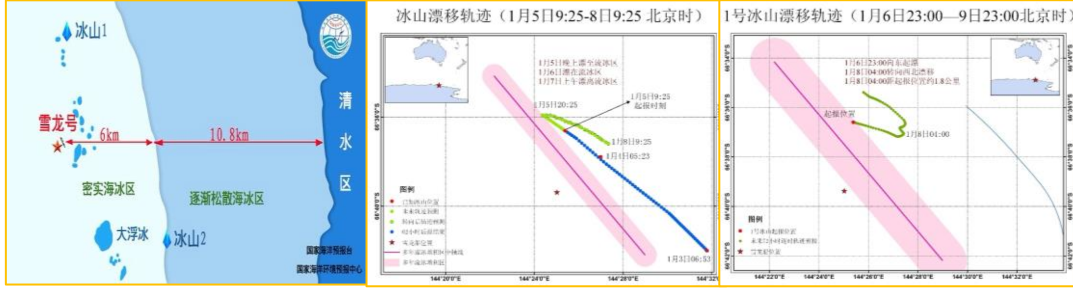
技术支持：上海地听信息科技有限公司



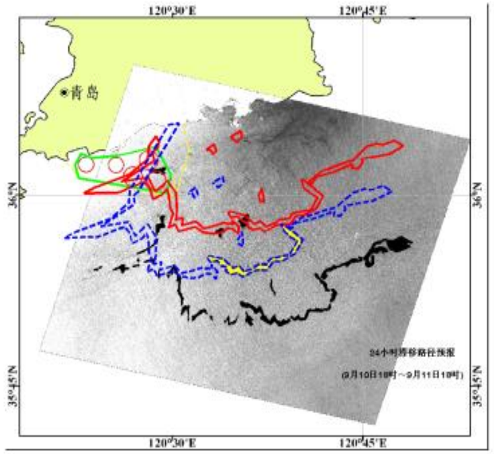
Three fishing boats sink near Xisha Islands in September 2013 with 88 persons on board due to Severe Typhoon Butterfly, 26 were saved



Two boat collisions off the Jiangsu coast with 14 people missing in Octorber 2013, the place of rescue is within the scope of forecasting

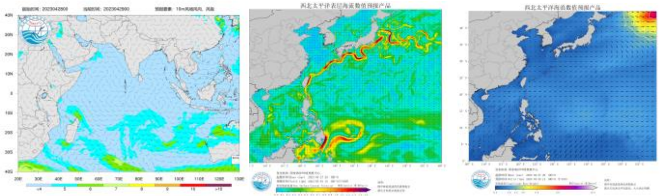


Iceberg drift trajectory prediction to provide technical support for Icebreaker "Xuelong" route planning in January 2014



Oil spill as a result of pipeline explosion near Dalian Bay in July 2011, 3D oil spill simulation was carried out

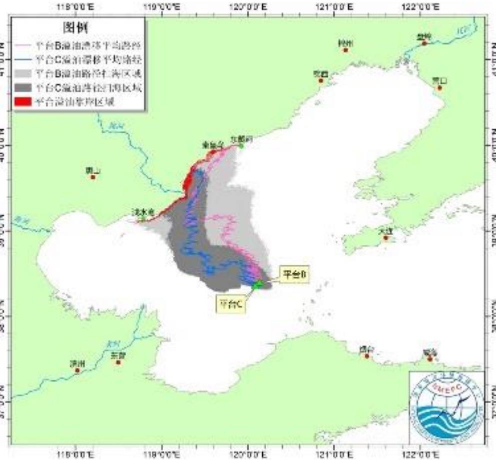
Observations of maritime emergencys obtained from ships, aircraft, and satellite



Marine environmental forecasting (wind, current, wave ...)

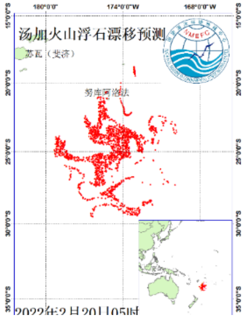
Maritime Emergency Forecasting

- On-site emergency treatment
- Environmental impact evaluation
- Determination of legal liability
- Sustainable development of marine economy

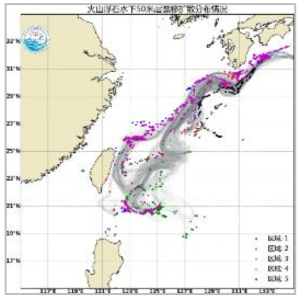


Oil spill emergency forecasting on the oil spill at Peilai 19 – 3 oil field in June 2011 was conducted, and provide support for environmental impact evaluation and legal liability determination

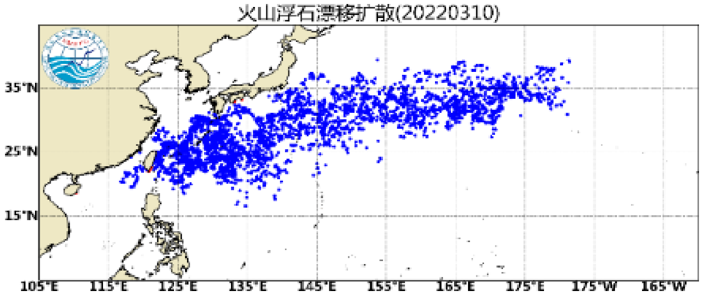
Vocanical pumice drift and diffusion prediction



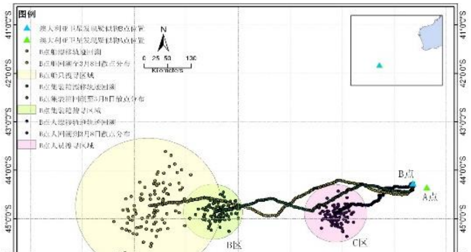
short-term (48-72h)



underwater modeling



mid- to long-term (1 to 3 months)



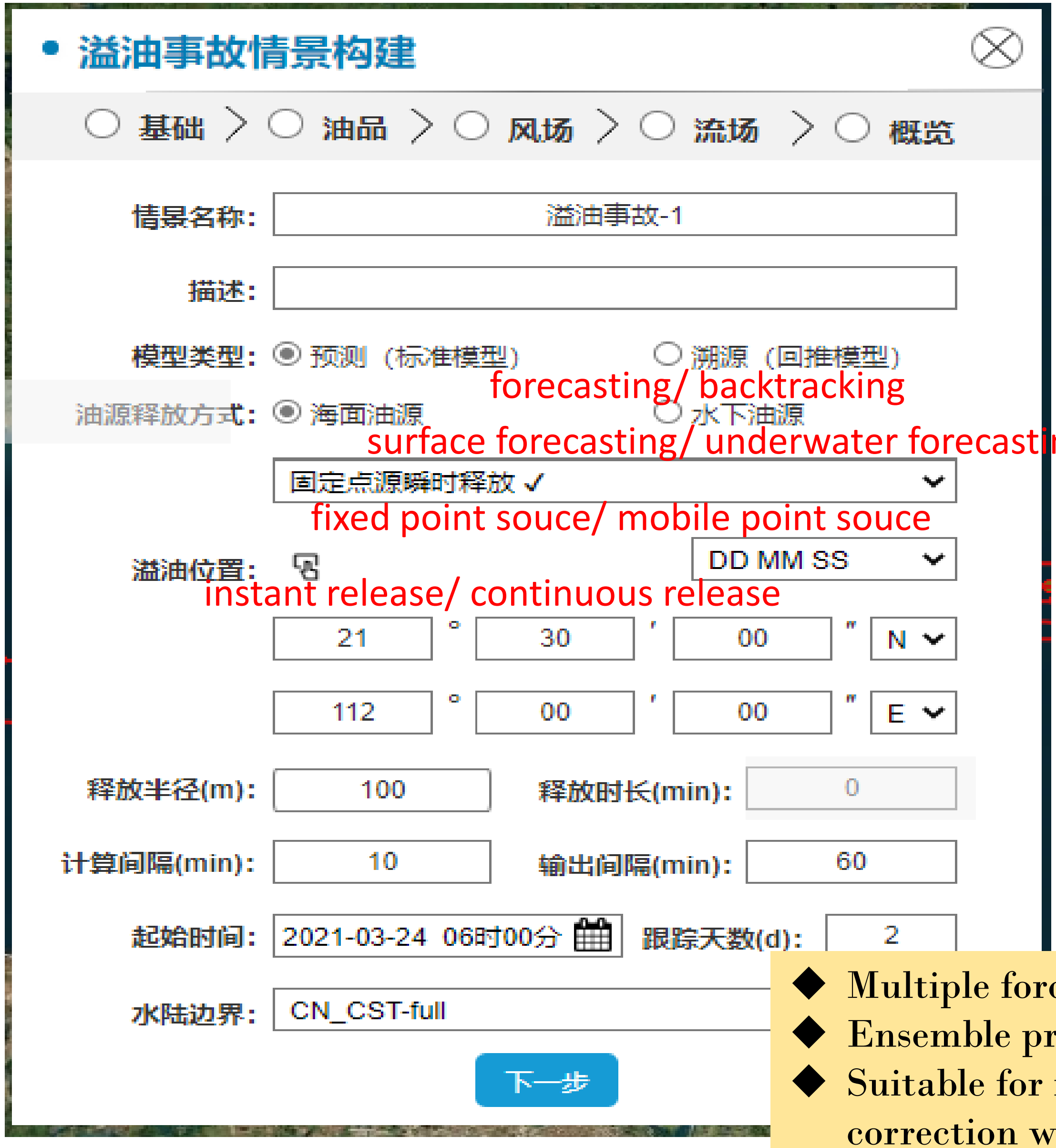
Backtracking of different suspicious objects of Flight MH370: person, vessel, cargo

We can make short-term forecasts for 5-7 days and long-term predictions on monthly or interannual scales.

02

Oil Spill Emergency Forecasting

2.1 Oil spill and hazardous chemical emergency forecasting platform



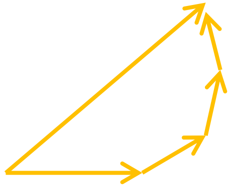
Human-computer interaction platform

- Multiple forcing fields
- Ensemble prediction
- Suitable for manual correction with *on-set* observation

The oil spill model is based on the "oil particle" model of Lagrange method. The motion of oil particles is mainly affected by sea current, sea surface wind, wave-induced current, self force and turbulent motion

Basic formula

$$\begin{cases} u_o = u_c + \alpha(u_a\cos\beta - v_a\sin\beta) + u_w + \langle u' \rangle \\ v_o = v_c + \alpha(u_a\sin\beta + v_a\cos\beta) + v_w + \langle v' \rangle \\ w_o = w_c + w_{ok} + \langle w' \rangle \end{cases}$$



Vertical velocity

$$\begin{cases} w_{ok} = \dfrac{gd^2(1-\rho_o/\rho_w)}{18\nu}, (d \le d_c) \\ w_{ok} = \sqrt{\dfrac{8}{3}gd(1-\rho_o/\rho_w)}, (d > d_c) \end{cases}, \quad \text{where} \quad d_c = \frac{9.52\nu^{2/3}}{g^{1/3}(1-\rho_o/\rho_w)^{1/3}}$$

Turbulant diffusion

Random walk

$$\begin{cases} u' = \xi\sqrt{c'A_m/\Delta t}\cos(2\pi\xi) \\ v' = \xi\sqrt{c'A_m/\Delta t}\sin(2\pi\xi) \\ w' = \xi\sqrt{c'K_h(K_{wave})/\Delta t} \end{cases} \qquad K_{wave} = 0.028\frac{H_S^2}{T}e^{-2\kappa z} \qquad \begin{cases} H_s = 2.12\times10^{-2}\times(u_a^2+v_a^2) \\ \overline{T} = 0.81\dfrac{2\pi\sqrt{u_a^2+v_a^2}}{g} \\ \kappa = \dfrac{2\pi}{\lambda} = \dfrac{4\pi^2}{gT^2} \end{cases}$$

1. Errors from the **wind field** and oil spill information (**releasing time**, location, *ect.*) are the main error sources of the oil spill model.

her resolution of the current field would further improve the acy of oil spill drift trajectory prediction.

2.2 Technical improvement in oil spill model

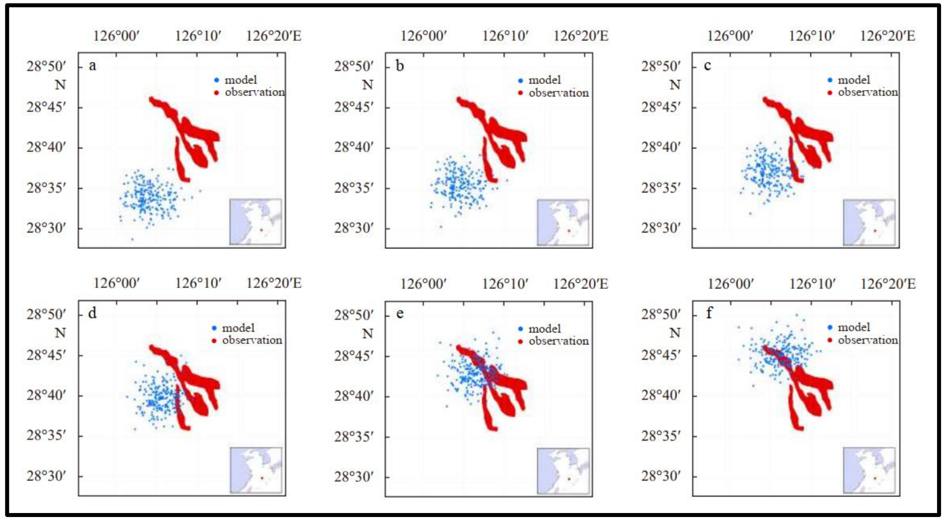
» 1. Consider the influence of Stokes drift on oil spill modeling

Group	No.	Wind	Current	Wind-drift factor/%	Stokes drift	Distance error/km
1	1	ECMWF	NMEFC-NWP	2	/	15.68
	2			2.5	/	12.88
	3			3	/	10.12
	4			4	/	6.24
	5			5	/	5.39
	6			6	/	8.72
2	7			3	$u_s(z)=\int_0^{\infty} 2\omega k(\omega)S(\omega)e^{2k(\omega)z}d\omega$	7.97
	8			4		2.97
	9			5		6.14
3	10			2	$u_s(z)=\frac{2}{g}\int_0^{2\pi}\int_0^{\infty}\omega^3\hat{k}e^{2kz}E(\omega,\theta)\mathrm{d}\omega\mathrm{d}\theta$	8.13
	11			2.5		1.03
	12			3		3.03

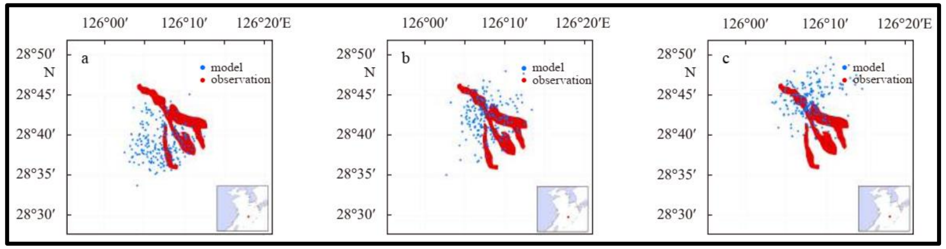
1. **Accuracy improves by 40%** with Stokes drift velocity taken into consideration in oil spill trajectory simulation, especially in mid- to long-term simulation.

2. Simulation using the Stokes drift velocity by **1D spectrum** is more suitable for operational forecasting (less computing time)

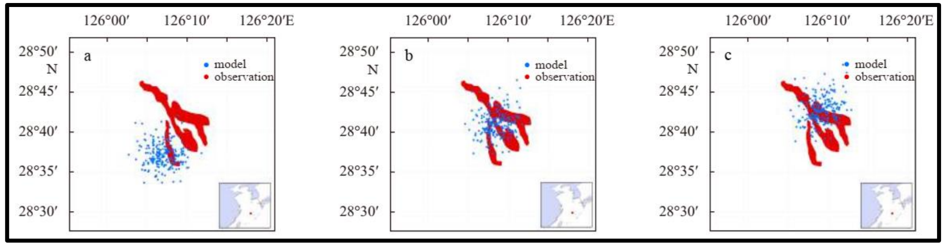
Exp.1 No Stokes drift considered



Exp.2 Calculated Stokes with 1D wave spectrum



Exp.3 Calculated Stokes with 2D wave spectrum



Yang Yiqiu, Li Yan, Li Juan, et a. The influence of Stokes drift on oil spills: Sanchi oil spill case. Acta Oceanol Sin, 2021, 11(40).

2.2 Technical improvement in oil spill model

» **2. Improvement of oil spill weathering model**

① More processes are taken into consideration

② Expand the oil library and coefficient database (up to **1441** kinds of oil and its related parameters)

Weathering model V1.0 → **Weathering model V2.0**

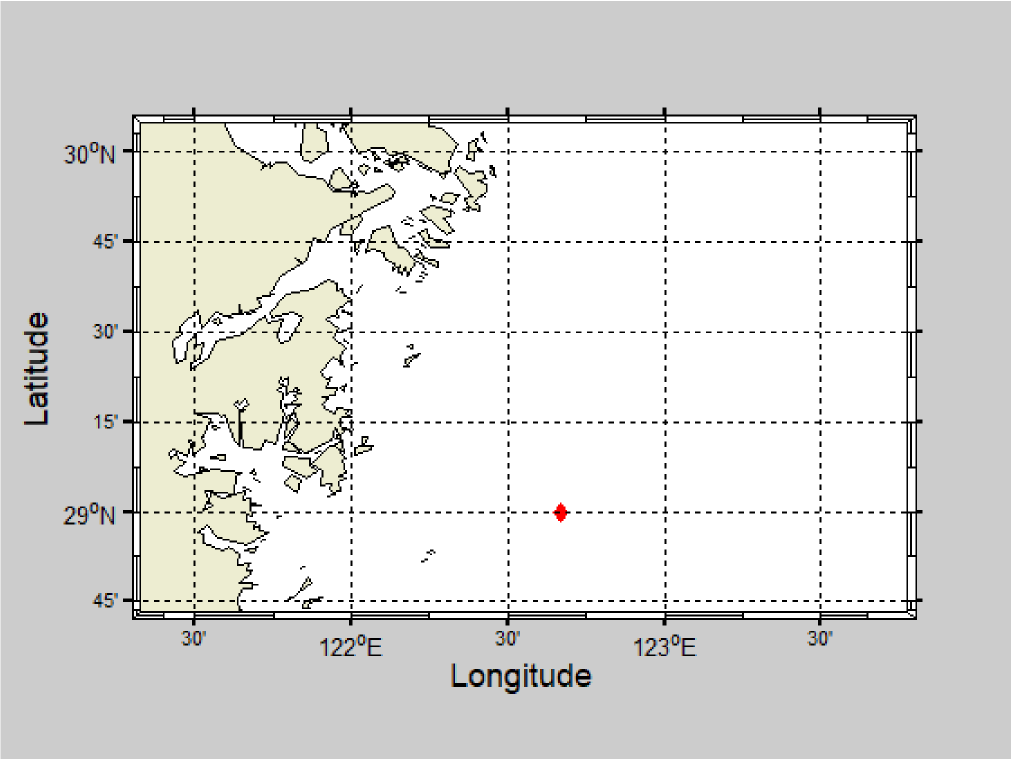
Weathering model V1.0		Weathering model V2.0	
Evaporation	$\theta' = \frac{k' A t}{V_0} = \frac{k' t}{\delta}$ $F_V = \ln\left[1 + B'\left(\frac{T_G}{T}\right)\theta' e^{\left(A' - B'\frac{T_0}{T}\right)}\right]\frac{T}{B' T_G}$	Vertical diffusion	$\frac{dm_d}{dt} = c_{oil} \cdot D_{ba}^{0.57} \cdot f_s \cdot F_{wc} \cdot d_0^{0.7} \cdot \Delta d$
Emulsification	$Y_W = \frac{1}{K_B}\left(1 - e^{-K_A K_B (1+U_W)^2 t}\right)$	Dissolution	$\frac{dDiss}{dt} = K \cdot f_s \cdot A_s \cdot S$ (g.h^{-1})
Density change	$\rho = (1 - Y_W)\left((0.6 \bullet \rho_0 - 0.34)F_V + \rho_0\right) + Y_W \bullet \rho_W$	Viscous change	$\mu = \mu_0 e^{c_T\left(1/T - 1/T_0\right)}$

2.2 Technical improvement in oil spill model

» **3. Mobile source oil spill modeling**

1. Oil spills from ships are getting more frequent
2. The existing oil spill model cannot simulate scenarios of mobile source oil spills

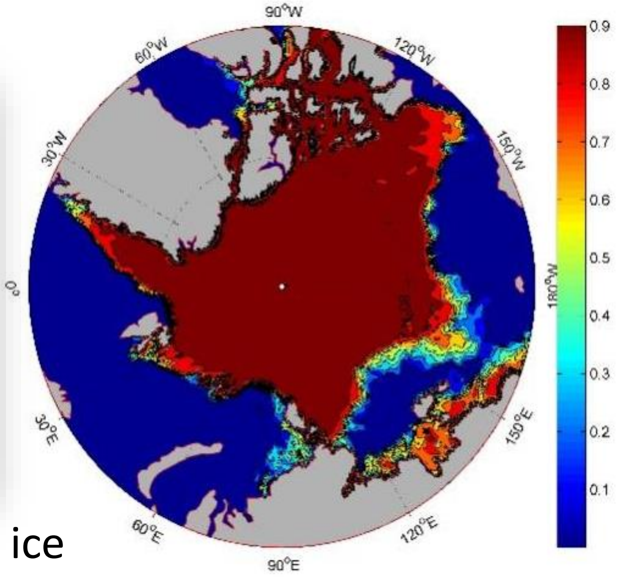
1. An individual module for the mobile point source information process was built
2. The input of moving velocity was added and kept in consistent with the model time step



2.2 Technical improvement in oil spill model

» 4. Development of oil spill modeling for ice region

- The ice module is built upon the existing oil spill model.
- The **ice coverage** and **ice velocity** are taken into consideration
- Model result is consistent with observation



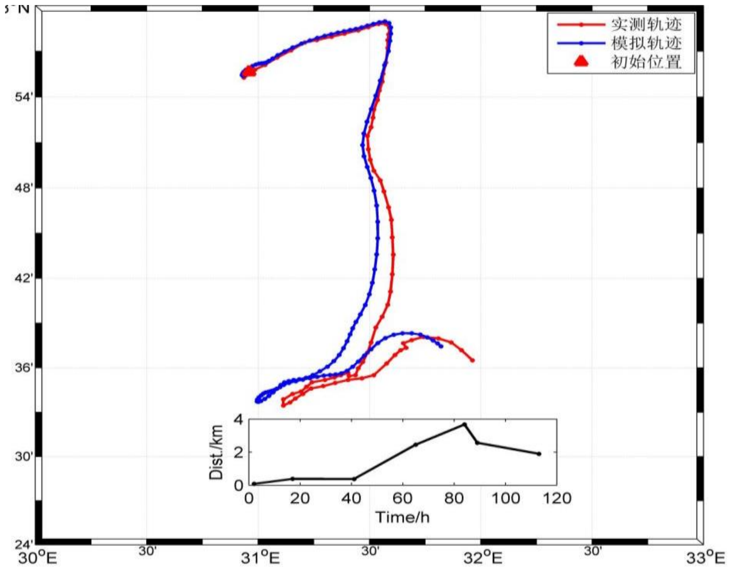
In the northern Bohai sea in China, sea ice disasters are huge threat to coastal oil field.

The velocity of the oil, v_{oil} at the water surface is given by:

$$\mathbf{v}_{oil} = k_{ice}\mathbf{v}_{ice} + (1 - k_{ice})(\mathbf{v}_{water} + f_w \mathbf{v}_{wind})$$

$$k_{ice} = \begin{cases} 0 & \text{if} \quad A < 0.3 \\ \frac{A-0.3}{0.8-0.3} & \text{if} \quad 0.3 \le A < 0.8, \\ 1 & \text{if} \quad 0.8 \le A \end{cases}$$

where v_{ice} and v_{water} are the velocity vectors of the ice and surface water, respectively, and A is the fractional ice cover.



The modeled trajectory is basically consistent with the measured trajectory, and the **distance error within the first 40 hours is less than 0.5 km.** The results show that the model is reliable

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03

Search and Rescue Emergency Forecasting

Ocean Predict

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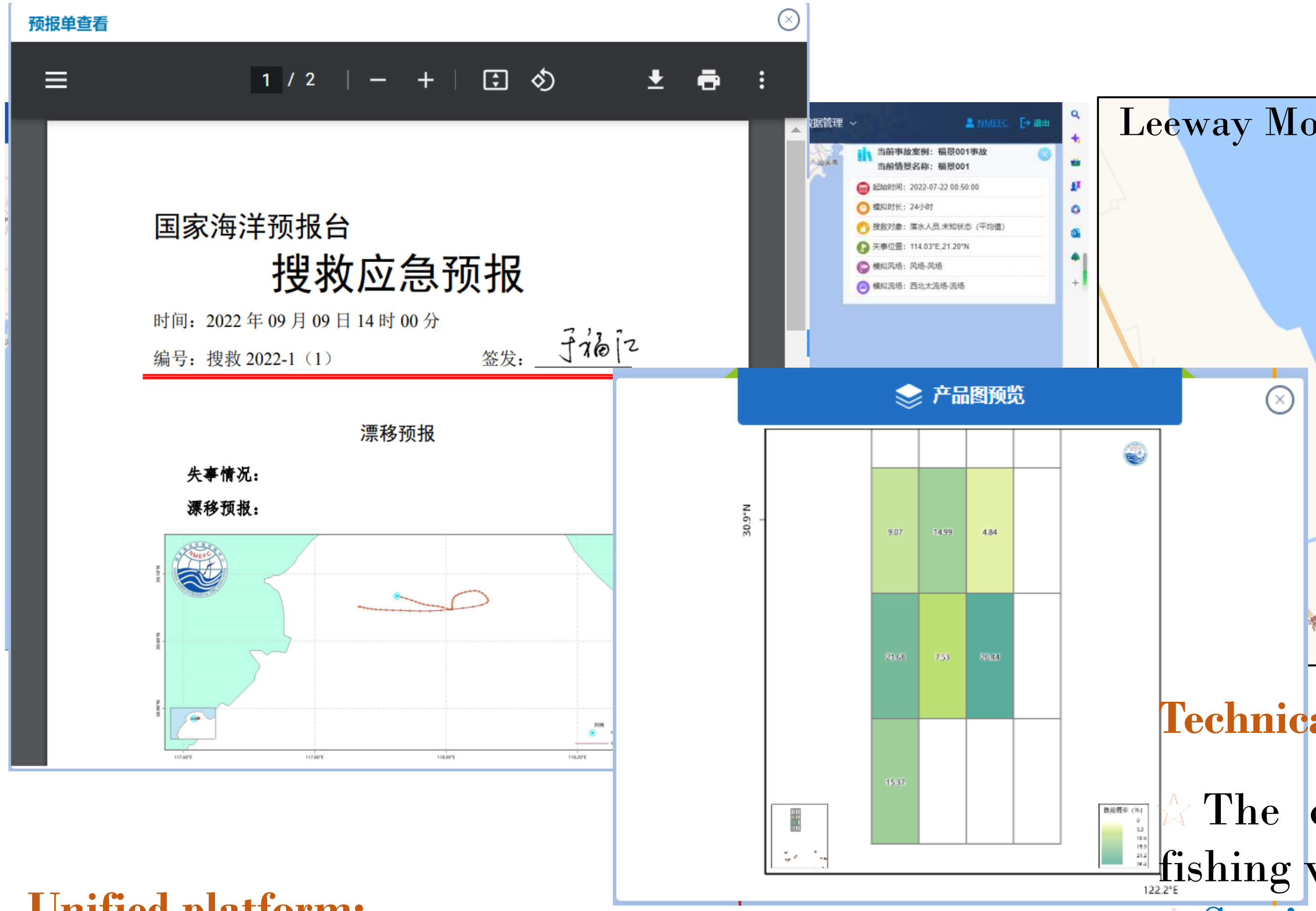
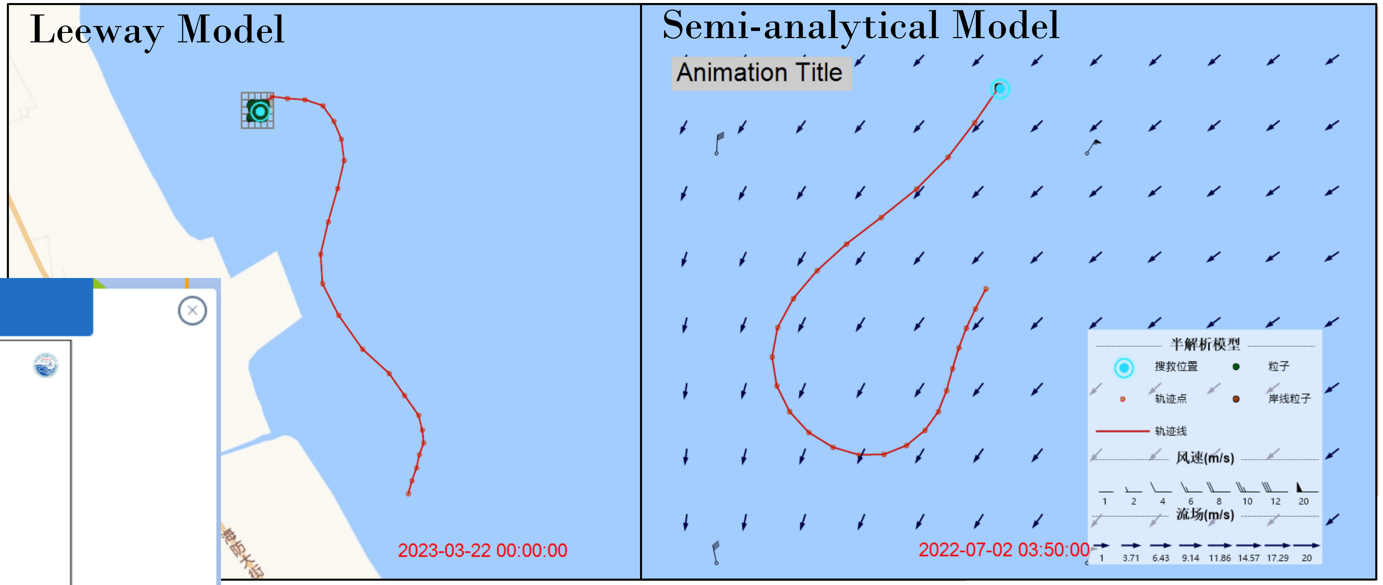
3.1 Search and rescue (SAR) emergency forecasting platform





Technical improvements:

- The characteristic drift coefficient database for typical fishing vessels in China was constructed
- **Semi-analytical model** was developed with expanded marine target coefficient database
- The influence of **wave** on large vessels is considered
- The ratio of the above-sea lateral projection area to the below-sea lateral projection area (**RAB**) is considered

Unified platform:

The platform integrates three types of SAR models: the Linear model, the Leeway model, and the Semi-analytical model into the same platform.

3.2 Improvements in the SAR model

» **1. Drift experiments on typical targets in China seas**

Typical fishing vessels in China, Dummy, Raft…

Open sea tests

Enriched marine target coefficient database that applicable to the China's maritime search and rescue:
Up to 93 leeway target types including human body in various postures in water, life rafts, small craft, and typical commercial fishing vessels, etc.

3.2 Improvements in the SAR model

» 2. POPC（the probability of positive crosswind）

When using Monte Carlo methods to predict search and rescue areas, the ratio of crosswind drift velocity：
- CWL(crosswind component of leeway) and +CWL is generally set to **50%**.

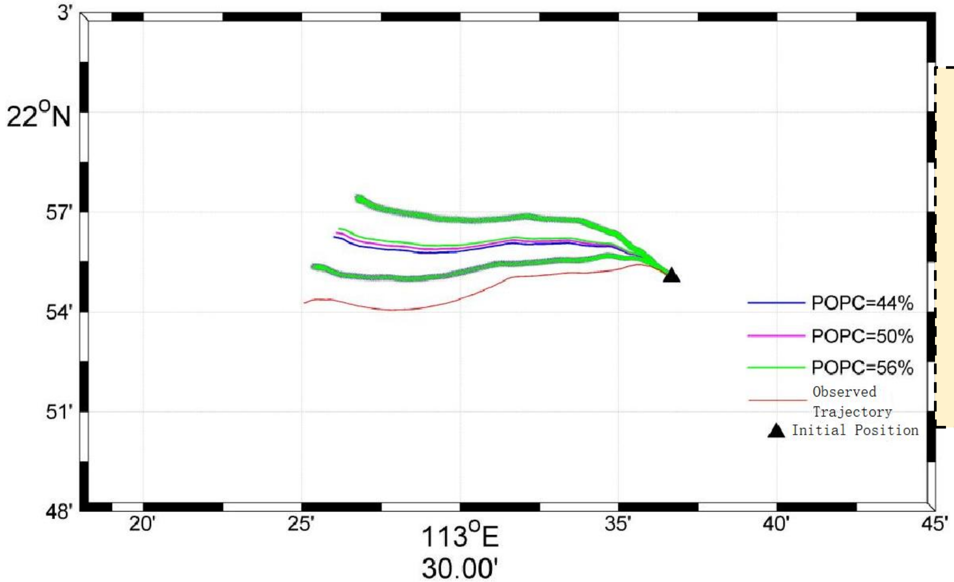
When the number of observed samples is sufficient, the probability of positive crosswind (POPC) can be added to the Leeway model.

Tab. The Mean Distance Error of three examples of POPC values

Object		case1 (Number of +CWL samples)	case2 (50%)	case3 (Number of -CWL samples)
Offshore fishing boats	POPC	popc=54%	popc=50%	popc=46%
	Mean Distance Error	0.7146	0.7099	0.7079
Vertical dummy	POPC	popc=56%	popc=50%	popc=44%
	Mean Distance Error	2.3951	2.2530	2.1083
Horizontal dummy	POPC	popc=69%	popc=50%	popc=31%
	Mean Distance Error	4.3492	4.3658	4.4014
Half loaded life raft	POPC	popc=33%	popc=50%	popc=67%
	Mean Distance Error	4.0903	3.9181	3.8191
Fully loaded life raft	POPC	popc=32%	popc=50%	popc=68%
	Mean Distance Error	2.7991	2.7315	2.6732

Tab. Number of observed samples with +CWL and -CWL of the object

Object	Number of +CWL samples (proportion)	Number of -CWL samples (proportion)
Offshore fishing boats	60（54%）	51（46%）
Vertical dummy	233（69%）	103（31%）
Horizontal dummy	203（56%）	159（44%）
Half loaded life raft	99(33%)	197(67%)
Fully loaded life raft	95(32%)	204(68%)



Trajectory diagrams of three POPC settings for horizontal dummies

From the perspective of mean distance error, the result is better when POPC is set to -CWL value. Next, more sample data is needed to prove this result.

3.2 Improvements in the SAR model

» 3. Semi-analytical model

- A semi-analytical model based on **geometric feature parameters** of ships is established (force analysis)
- The ratio of the above-sea lateral projection area to the below-sea lateral projection area (**RAB**) is considered

Force analysis

$$\vec{F}_{w} + \vec{F}_{a} + \vec{F}_{wa} + \vec{F}_{g} + \vec{F}_{b} = m\left(\frac{d\vec{V}_{0}}{dt} + \vec{f}\times\vec{V}_{0}\right)$$

water drag $$\vec{F}_{w} = \frac{1}{2}\rho_{w} C_{w} A_{w} \left|\vec{V}_{rw}\right| \vec{V}_{rw}$$

wind drag $$\vec{F}_{a} = \frac{1}{2}\rho_{a} C_{a} A_{a} \left|\vec{V}_{ra}\right| \vec{V}_{ra}$$

surface wave reflection force $$\vec{F}_{wa} = \frac{1}{4}\rho_{w} g L H^{2}$$

$\vec{V}_0$	velocity
$\vec{f}$	Coriolis force parameter
m	object mass
t	drift duration
A_w, A_a	areas in water or in air
L	length of object

RAB (A_w, A_a), wind drag coefficient (C_w), and water drag coefficient (C_a) are the most essential parameters

Settings:

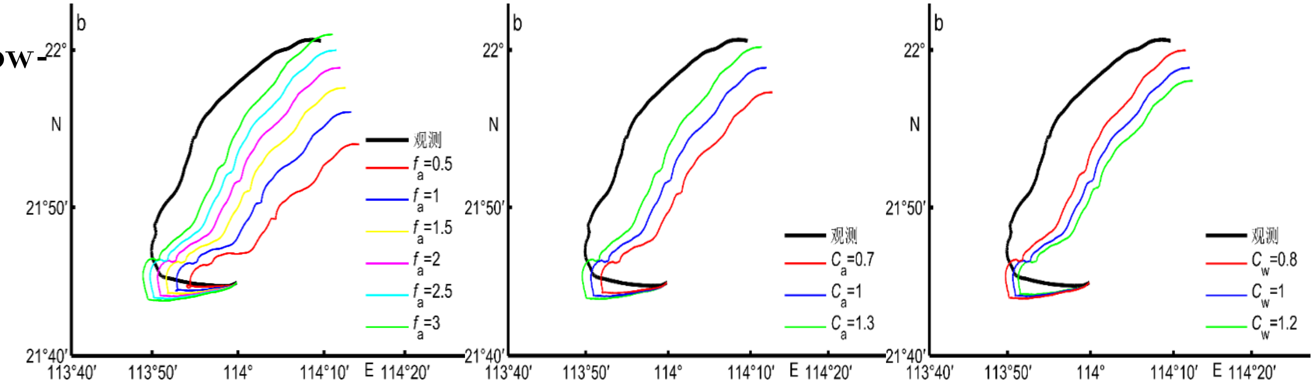
- RAB f_a : 0.5—3
- Wind drag C_a : 0.7—1.5
- Water drag C_w : 0.8—1.2

Semi-analytical Model wind slopes:

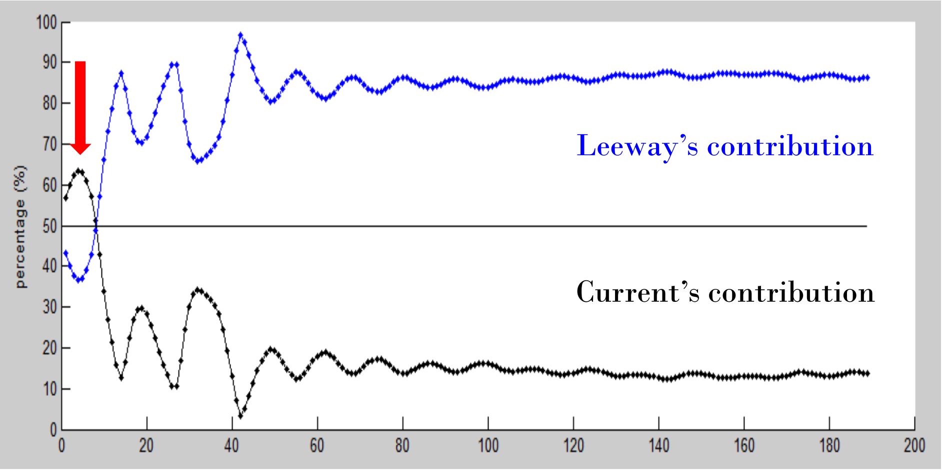
1.88%—7.76%

Classic Leeway Model DWL slope:

1.8%—6.54%



RAB | Wind drag coefficient | Water drag coefficient



When the wind speed exceeds 5m/s, the influence of current is much lower than wind and wave on the drift trajectory

04

Applications in Maritime Emergency Response

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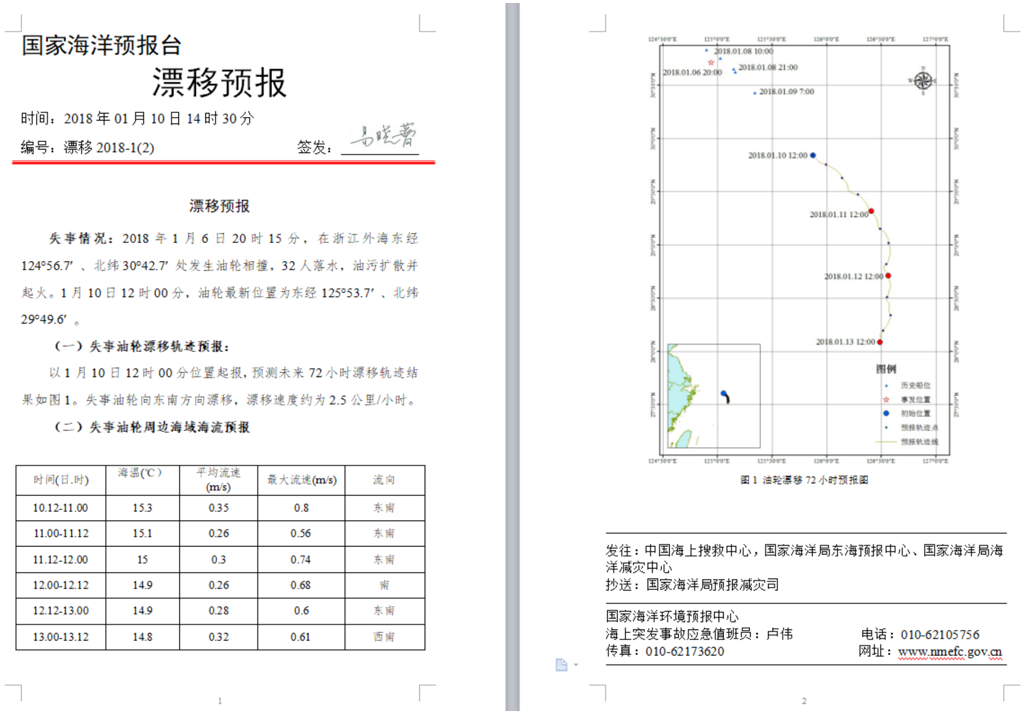
4.1 Applications in the tanker Sanchi oil spill emergency

» 1. Oil spill forecasting service for tanker Sanchi — drift, diffusion and weathering

On January 6th 2018, the Panama-registered oil tanker Sanchi , loaded with 136,000 tons of condensate oil and 1,900 tons of bunker oil, collided with the Hong Kong cargo ship at 30°42′N, 124°56′E. The oil tanker was burning till January 14th , and sank at 28°22′N, 125°55′E, with oil spilled into the sea.

- The emergency forecast of the future 72-hour of the oil distribution was performed and published on daily basis from 14 January to 2 February.



国家海洋预报台

漂移预报

时间：2018 年 01 月 10 日 14 时 30 分

编号：漂移 2018-1(2)　　　签发：

漂移预报

失事情况： 2018 年 1 月 6 日 20 时 15 分，在浙江外海东经 124°56.7′ 、北纬 30°42.7′ 处发生油轮相撞，32 人落水，油污扩散并起火。1 月 10 日 12 时 00 分，油轮最新位置为东经 125°53.7′ 、北纬 29°49.6′ 。

（一）失事油轮漂移轨迹预报：

以 1 月 10 日 12 时 00 分位置起报，预测未来 72 小时漂移轨迹结果如图 1。失事油轮向东南方向漂移，漂移速度约为 2.5 公里/小时。

（二）失事油轮周边海域海流预报

时间(日.时)	海温(℃)	平均流速 (m/s)	最大流速(m/s)	流向
10.12-11.00	15.3	0.35	0.8	东南
11.00-11.12	15.1	0.26	0.56	东南
11.12-12.00	15	0.3	0.74	东南
12.00-12.12	14.9	0.26	0.68	南
12.12-13.00	14.9	0.28	0.6	东南
13.00-13.12	14.8	0.32	0.61	西南

1

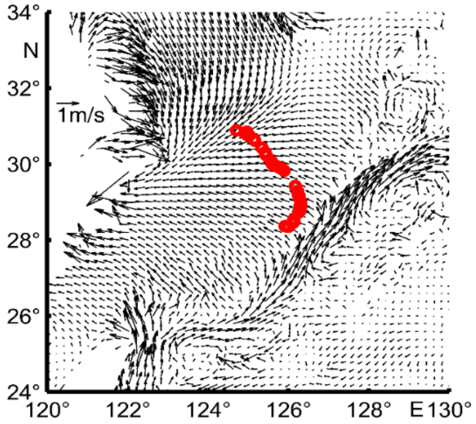
图 1 油轮漂移 72 小时预报图

发往：中国海上搜救中心，国家海洋局东海预报中心、国家海洋局海洋减灾中心
抄送：国家海洋局预报减灾司

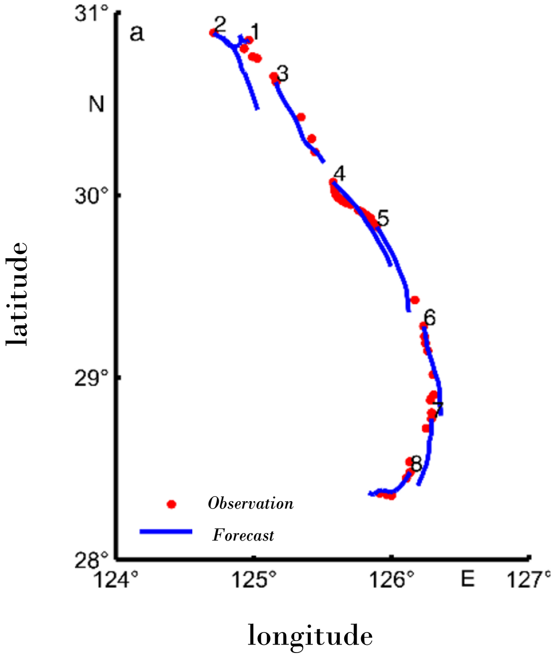
国家海洋环境预报中心
海上突发事故应急值班员：卢伟　　电话：010-62105756
传真：010-62173620　　网址：www.nmefc.gov.cn

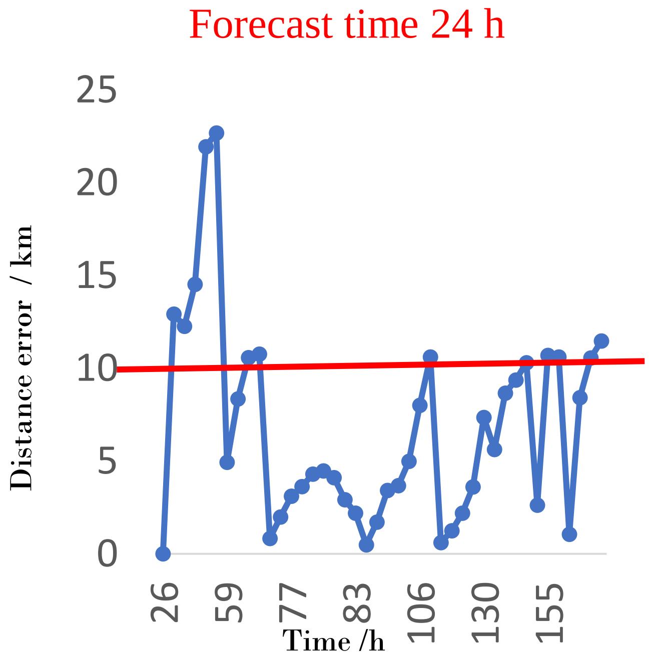
2

Sanchi caught fire after the collision



Observation trajectory

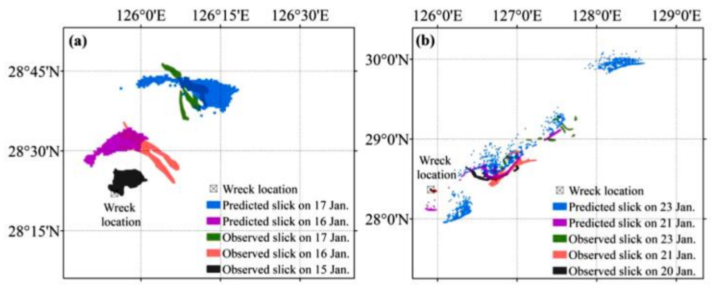




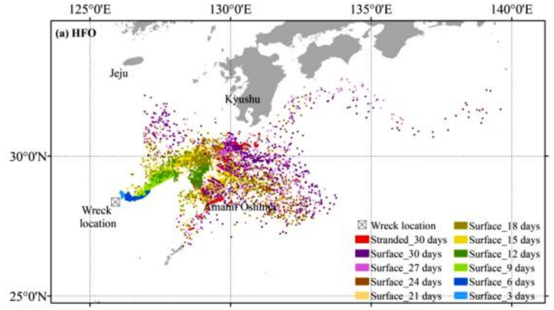
4.1 Applications in the tanker Sanchi oil spill emergency

- A long term fate and behavior for condensate and bunker oil during January and February was performed.
- The leakage from the submerged tanker was also investigated.
- A validation study was carried out for the wind, current, oil distribution and shoreline hits.

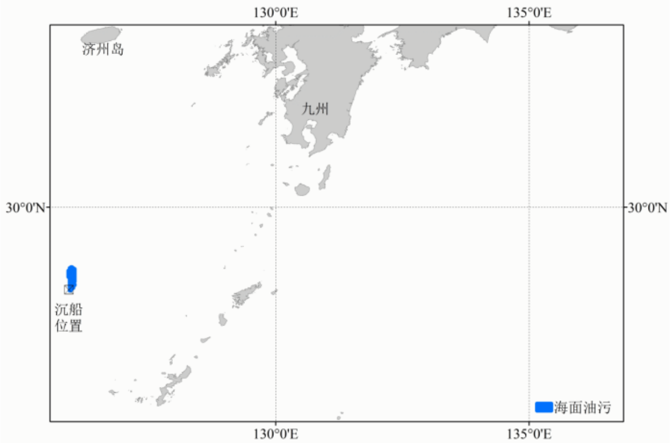
The forecasting conclusions have successfully **supported the decision making** for the response of the *Sanchi* oil spill, as well as **environmental impact evaluation**.



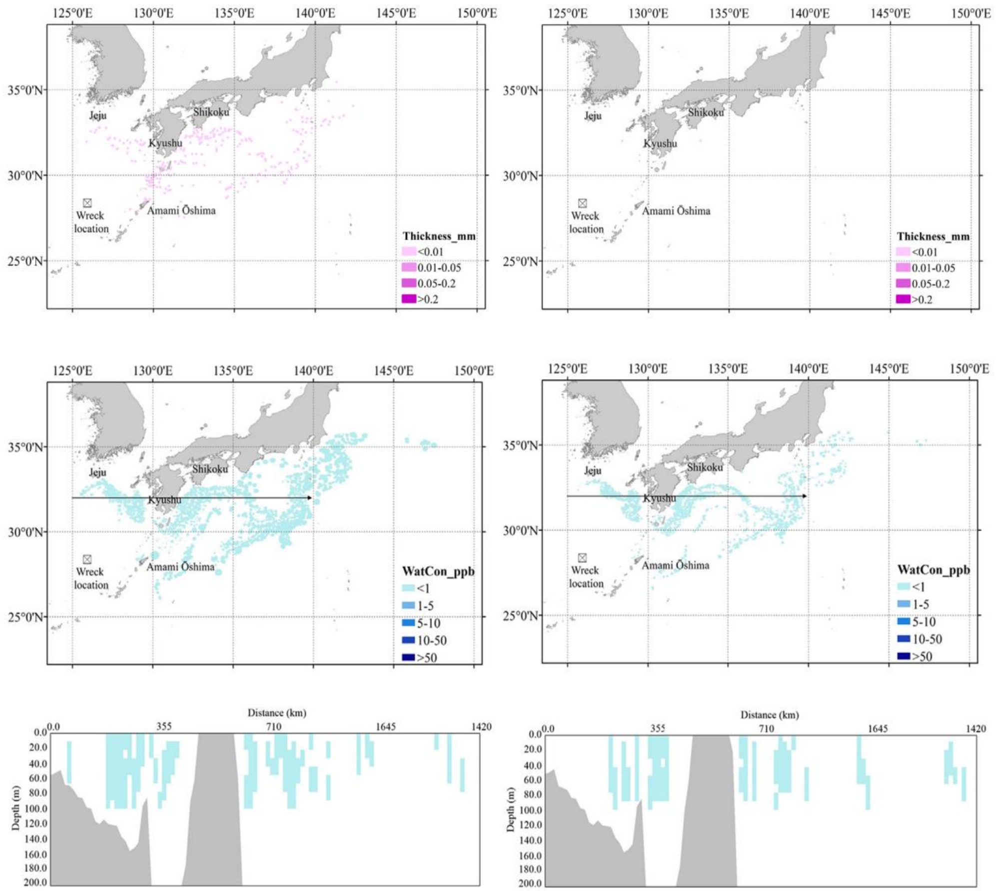
Validation of the forecasted surface slick against the satellite



Simulated accumulative distribution of heavy fuel oil



Prediction of Fuel oil drift and diffusion for 30 days



Comparisons of surface oil thickness (first row), bird's view of dispersed oil concentration (second row) in the water column, and the corresponding vertical view of the concentration for heavy fuel oil (left column) and condensate (right column) on 1 March

Qingqing Pan, Xueming Zhu, Liying Wan, Yun Li, Xiaodi Kuang, Jingui Liu, Han Yu. (2021). Operational forecasting for Sanchi oil spill, *Applied Ocean Research*, 108.

Qingqing Pan, Han Yu, Per S. Daling, Yu Zhang, Mark Reed, Zhaoyi Wang, Yun Li, Xu Wang, Lunyu Wu, Zhihua Zhang, Haipeng Yu, Yarong Zou. (2020). Fate and behavior of Sanchi oil spill transported by the Kuroshio during January–February 2018, *Marine Pollution Bulletin*, 152.

4.2 Applications in the search for Chinese offshore fishing vessel

» 2. Assistance in the search for the Chinese offshore fishing vessel 'Lupengyuan Fishing 028'

On May 16, 2023 at 03:00, the Chinese offshore fishing vessel "Lupeng Yuanyu 028" capsized in the waters near 77 ° 05 ′ E and 5 ° 46 ′ S in the central Indian Ocean, and 39 people on board were missing.

NMEFC activated emergency response on the morning of May 17th, providing a total of 11 forecast products for the drift trajectory of drowning personnel and the surrounding marine environment.

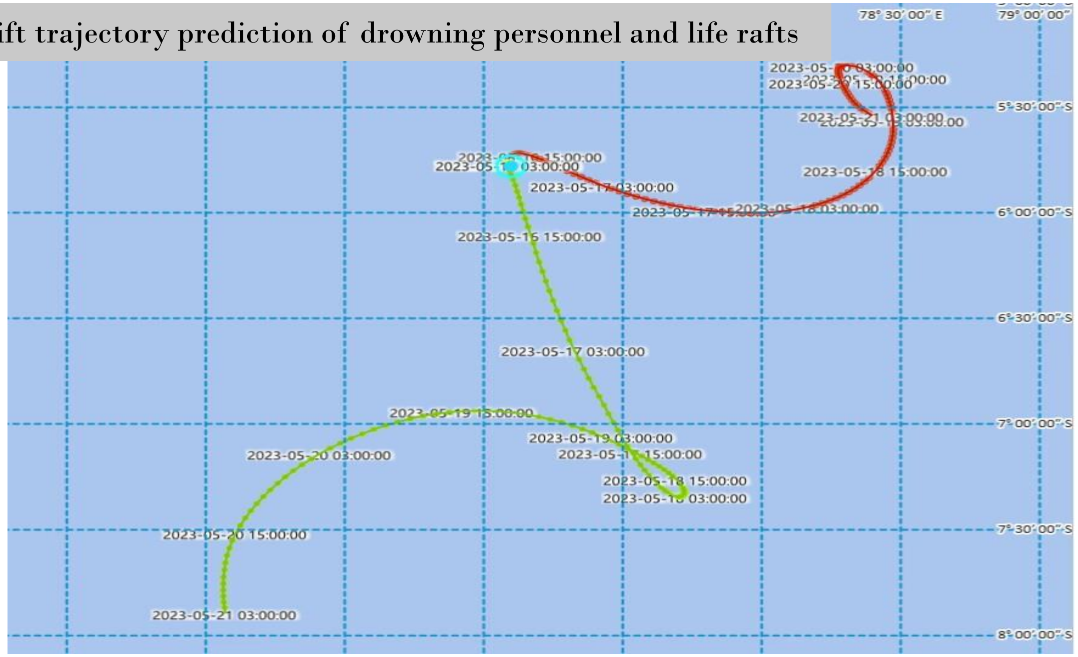
1. To simulate the drift trajectory and search area of drowning personnel

2. To simulate the drift trajectory and search area of life raft

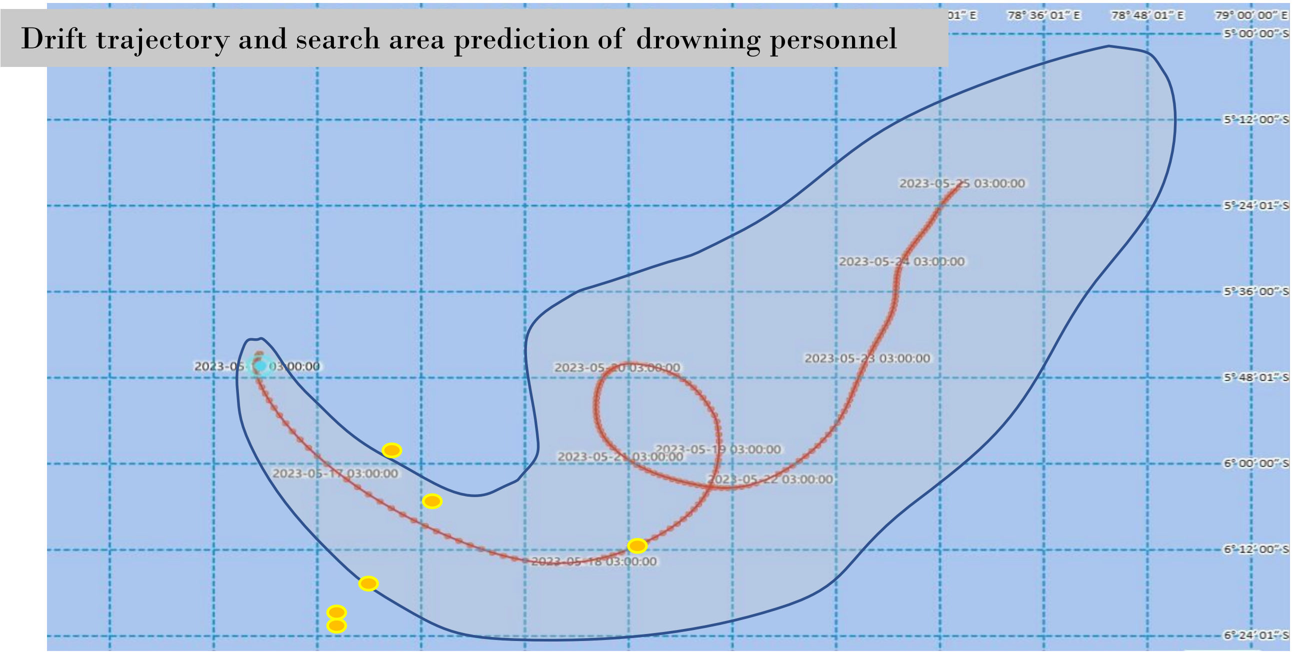
➢Based on the location of the bodies of the drowning person discovered on the 18th, adjust the parameters and provide a search and rescue forecast based on the new parameters.

➢The location of the bodies of the drowning personnel discovered was near the search area, providing timely and effective technical support for maritime rescue.

Drift trajectory prediction of drowning personnel and life rafts



Drift trajectory and search area prediction of drowning personnel



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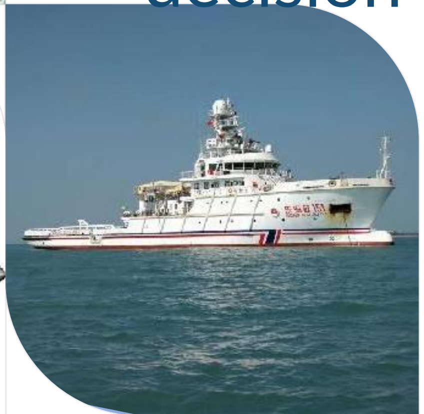
Future Works

5.1 The Future Development of Search and Rescue , Oil Spill Technologies

- Research on SAR Technology: Jibing phenomenon, further research on POPC

- A platform that integrates various search and rescue forces into an auxiliary decision-making system



Oil containment fence

Oil Spill Dispersant

Oil spill incineration

- Research on Typical Emergency Response Measures for Oil Spill Behavior and Fate Prediction Technology

Thank you!

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