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

Miaoyin Zhang
National Marine Environmental Forecasting Center

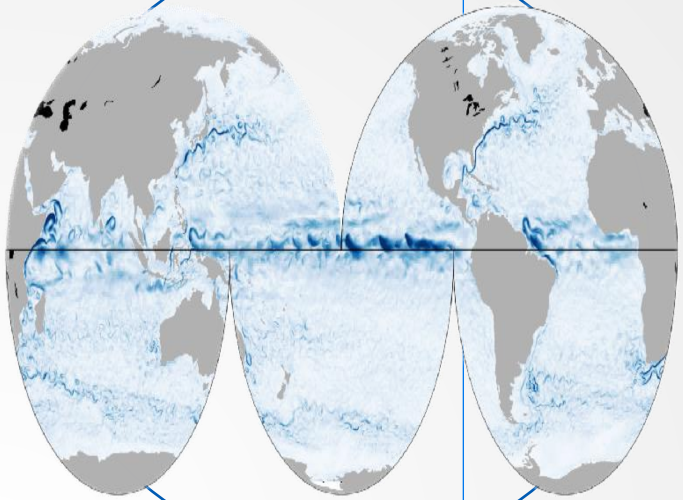
Montreal, Canada

May 3rd, 2023

CONTENT

01

Background Introduction



1.1 Demands for operational maritime emergency forecasting systems

- Maritime hazards occur more frequently in China along with the rapid development of marine economy and intensified utilization of coastal zones

Tianjin port explosion

Sanchi oilspill

"Fujing 001" shipwreck

Shipwreck search and rescue

- The climate change increases the likelihood and severity of extreme event like extreme heat, precipitation, tropical cyclones, and strom surges. In 2022, the top three marine disasters are storm surge, sea wave, and red tide in China, which caused a total of 35,062,228 USD of direct economic losses [1].

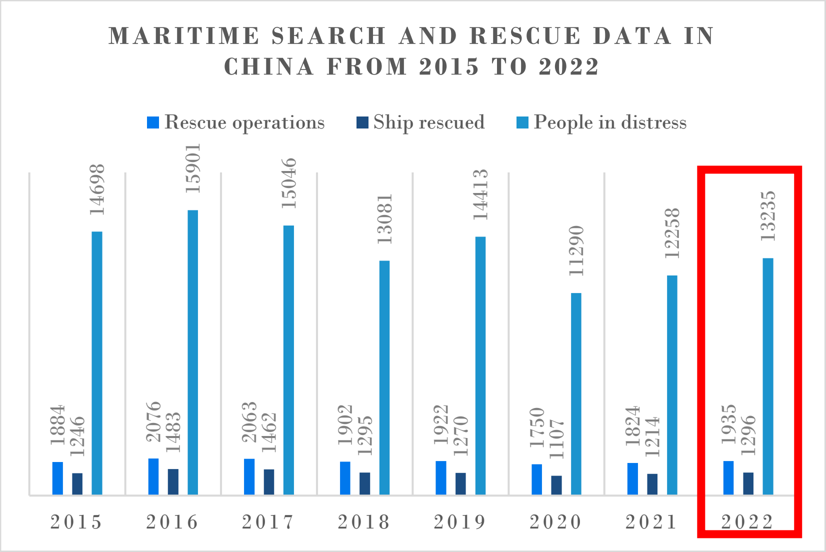
1 Ministry of Transportation of the People's Republic of China.National maritime search and rescue situation Report [EB/OL]. (2022-11-10) [2022-11-10].https://xxgk.mot.gov.cn/2020/jigou/zghssjzx/202302/t20230227_3765122.html

1.1 Demands for operational maritime emergency forecasting systems

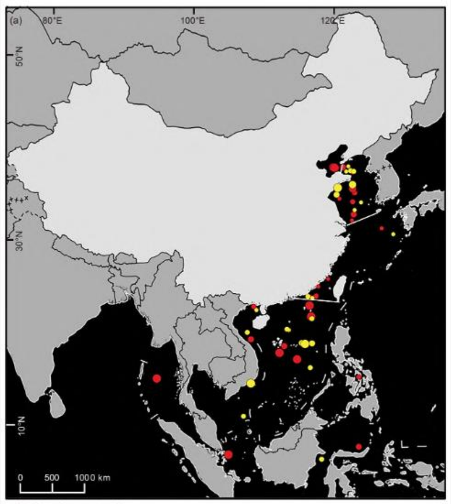
- Maritime hazards pose threats to the environment and human activities and proverty

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].



"Bingo" shipwreck in 2013



Oil spill from the damaged "Symphony"

- Non-emulsified oil spill (26 times)
- Emulsified oil spill (31 times)

2 Liu, J. & Lu, Yingcheng & Ding, Jing & Suo, Ziyi & Liang, Chao. (2022). Oil spills in China Seas revealed by the national ocean color satellites. Chinese Science Bulletin. 67. 10.1360/TB-2021-0992.

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.

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

1980s-2010s

Boost of physical models

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

Maritime emergency forecasting models began to develop

2008-2015

Preliminary research

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

Enrich characteristic coefficient database
Consider more complex physical and chemical processes

2015-2022

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

Coupled with the new Mass Conservation Ocean Model (MaCOM)

2023-

Explosive Growth

Maritime emergency forecasting system based on GPU

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

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

1.2 Requirements for the operational emergency forecasting

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

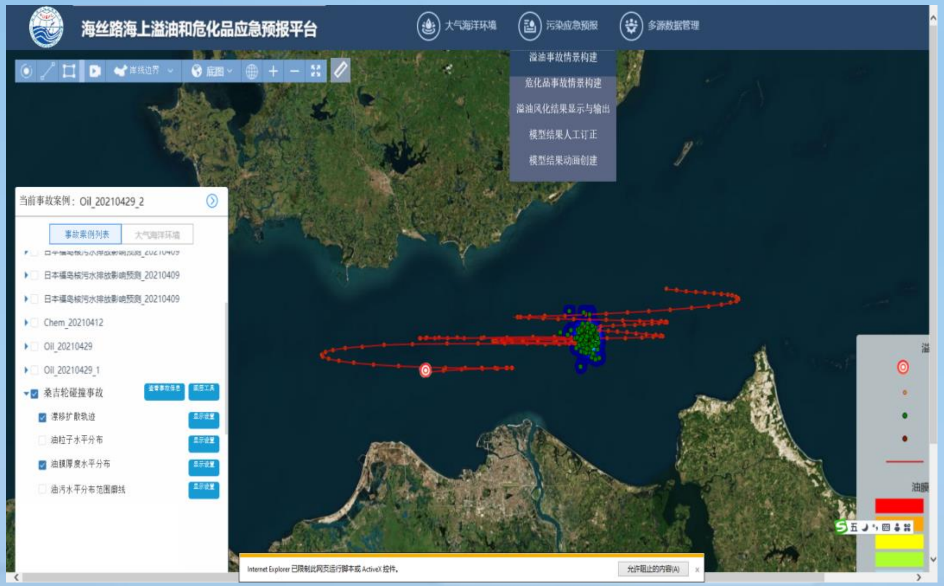
02 **Friendly to multi-source data**

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

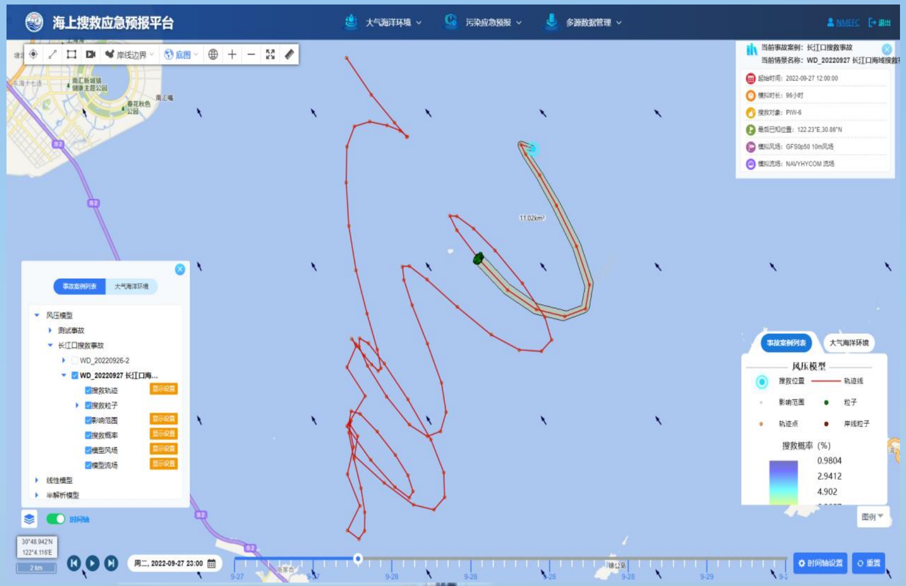
NMEFC 退出

海上事故应急预报平台

Maritime Emergency Forecasting Platform

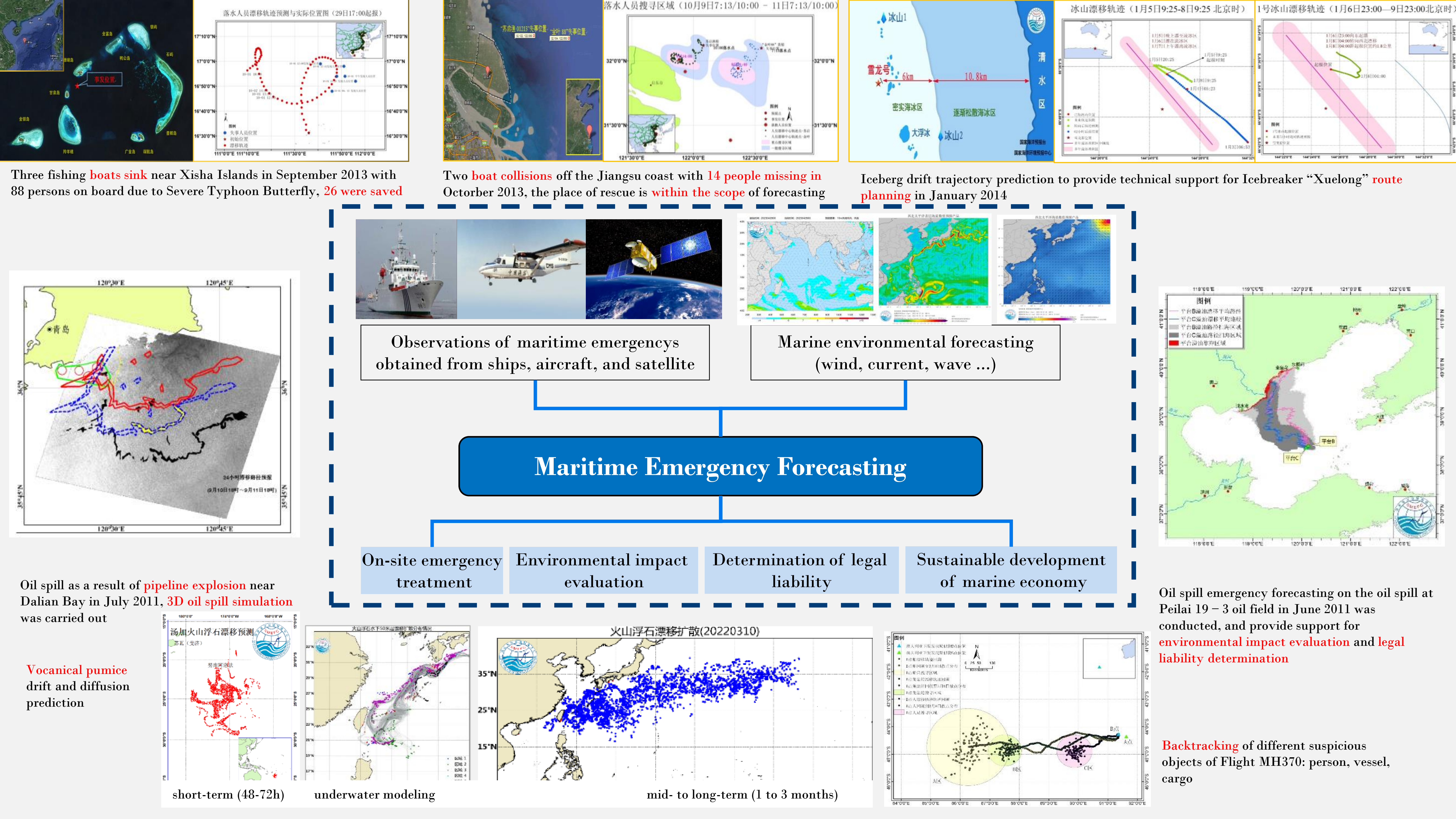


Oil Spill and Hazardous Chemical Emergency Forecasting Platform



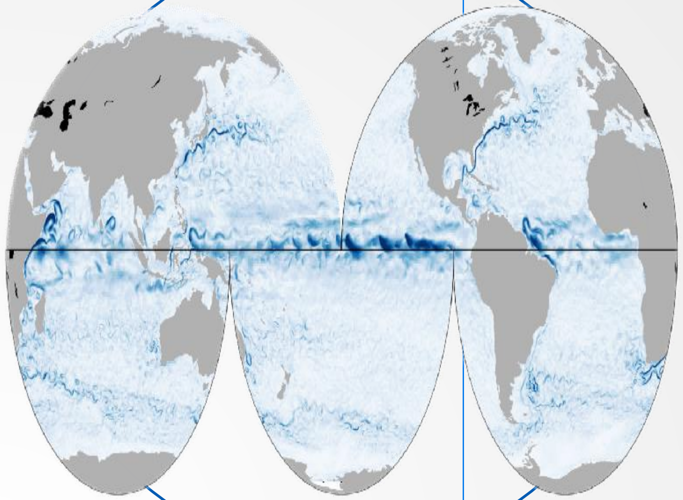
Search and Rescue Emergency Forecasting Platform

技术支持：上海地听信息科技有限公司

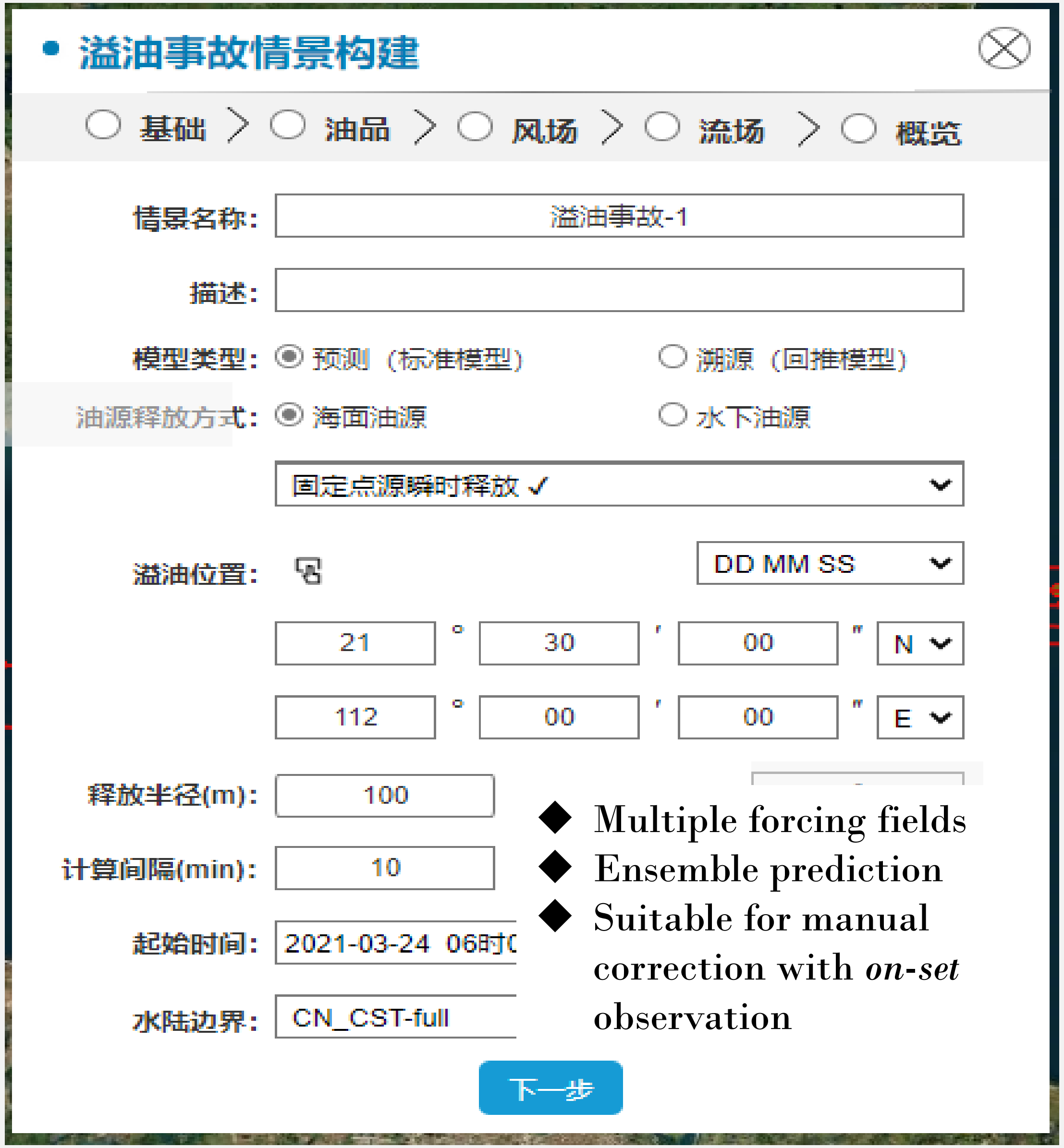

Three fishing boats sink near Xisha Islands in September 2013 with 88 persons on board due to Severe Typhoon Butterfly, 26 were saved
Two boat collisions off the Jiangsu coast with 14 people missing in Octorber 2013, the place of rescue is within the scope of forecasting
Iceberg drift trajectory prediction to provide technical support for Icebreaker “Xuelong” route planning in January 2014
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 as a result of pipeline explosion near Dalian Bay in July 2011, 3D oil spill simulation was carried out
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
冰山1
冰山2
雪龙号
6km
10.8km
清水区
火山浮石漂移扩散(20220310)

02

Oil Spill Emergency Forecasting



2.1 Oil spill and hazardous chemical emergency forecasting platform



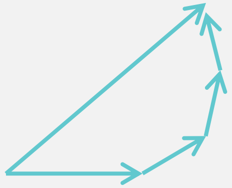
- Multiple forcing fields
- Ensemble prediction
- Suitable for manual correction with *on-set* observation

Human-computer interaction platform

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

$$\begin{cases} u' = \xi\sqrt{c' A_m / \Delta t}\cos(2\pi\xi) \\ v' = \xi\sqrt{c' A_m / \Delta t}\sin(2\pi\xi) \\ w' = \xi\sqrt{c' K_h(K_{wave}) / \Delta t} \end{cases}$$

$$K_{wave} = 0.028\frac{H_S^2}{T}e^{-2\kappa z}$$

$$\begin{cases} H_s = 2.12\times10^{-2}\times(u_a^2+v_a^2) \\ \overline{T} = 0.81\dfrac{2\pi\sqrt{u_a^2+v_a^2}}{g} \\ \kappa = \dfrac{2\pi}{\lambda} = \dfrac{4\pi^2}{gT^2} \end{cases}$$

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

2. **Higher resolution of the current field** would further improve the accuracy 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

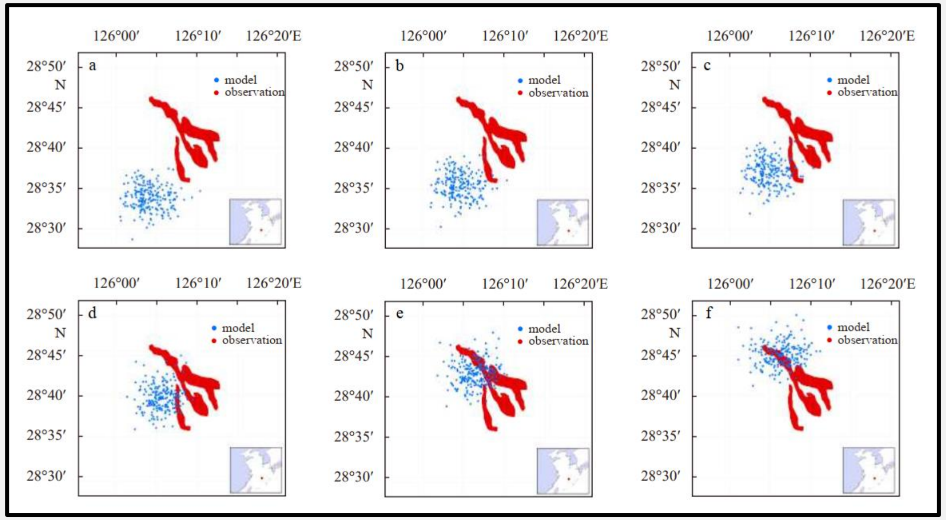
Group	No.	Wind	Current	Wind-drift factor/%	Stokes drift	Distance error/km
1	1	ECMWF	NMEFC-NWP	2	/	15.68
	2			2.5	/	12.88
	3			3	/	10.12
	4			4	/	6.24
	5			5	/	5.39
	6			6	/	8.72
2	7			3	$u_s(z) = \int_0^{\infty} 2\omega k(\omega) S(\omega) e^{2k(\omega)z} d\omega$	7.97
	8			4		2.97
	9			5		6.14
3	10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

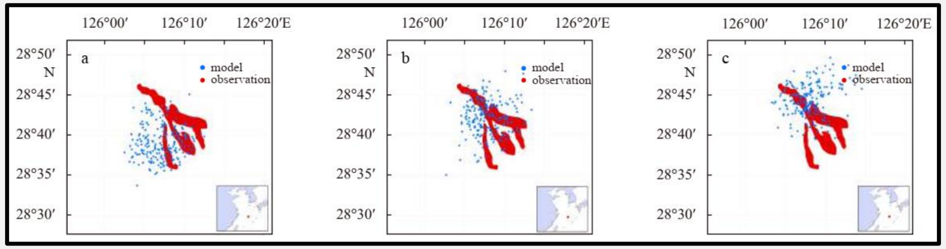
2. Simulation using the Stokes drift velocity by **1D spectrum** is more suitable for operational forecasting (less computing time)

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).

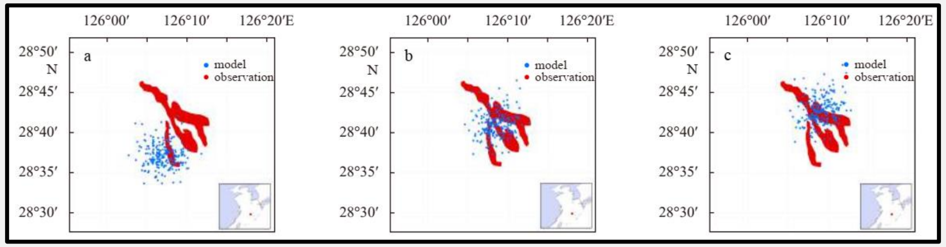
Exp.1 No Stokes drift considered



Exp.2 Calculated Stokes with 1D wave spectrum



Exp.3 Calculated Stokes with 2D wave spectrum



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 by introducing the **ADIOS oil database** from the US (up to **1441** kinds of oil and its related parameters)

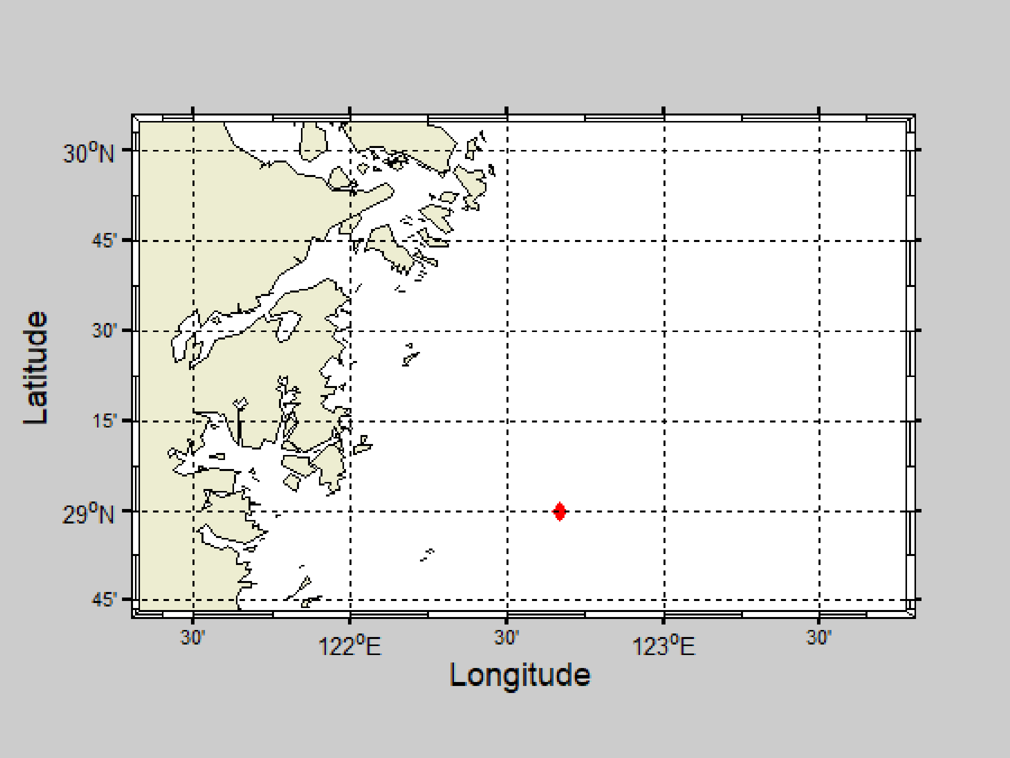
Weathering model V1.0		Weathering model V2.0	
Evaporation	$\theta' = \frac{k' At}{V_0} = \frac{k' t}{\delta}$ $\quad F_V = \ln\left[1 + B'\left(\frac{T_G}{T}\right)\theta' e^{\left(A' - B' \frac{T_0}{T}\right)}\right]\frac{T}{B' T_G}$	Vertical diffusion	$\frac{dm_d}{dt} = c_{oil} \cdot D_{ba}^{0.57}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

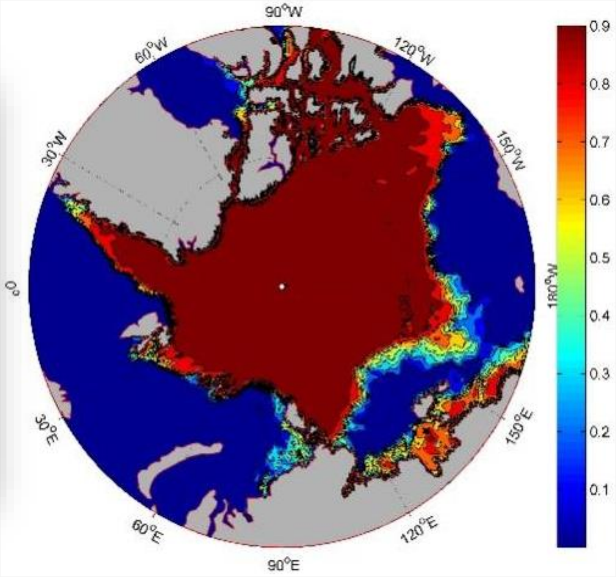
1. An individual module for the mobile point source information process was built
2. The input of moving velocity was added and kept in consistent with the model time step



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

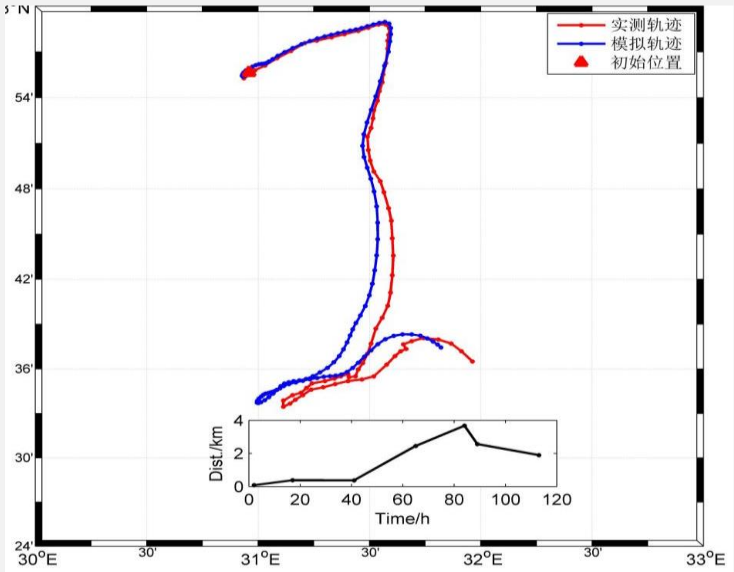


The velocity of the oil, v_{oil} at the water surface is given by:

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

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

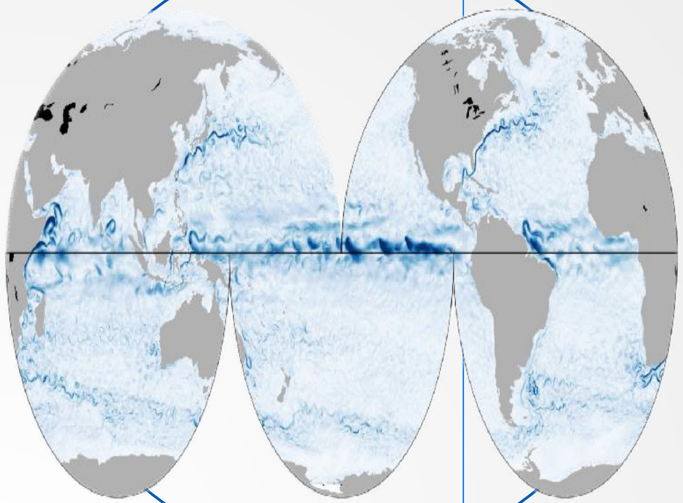
where v_{ice} and v_{water} are the velocity vectors of the ice and surface water, respectively, and A is the fractional ice cover.



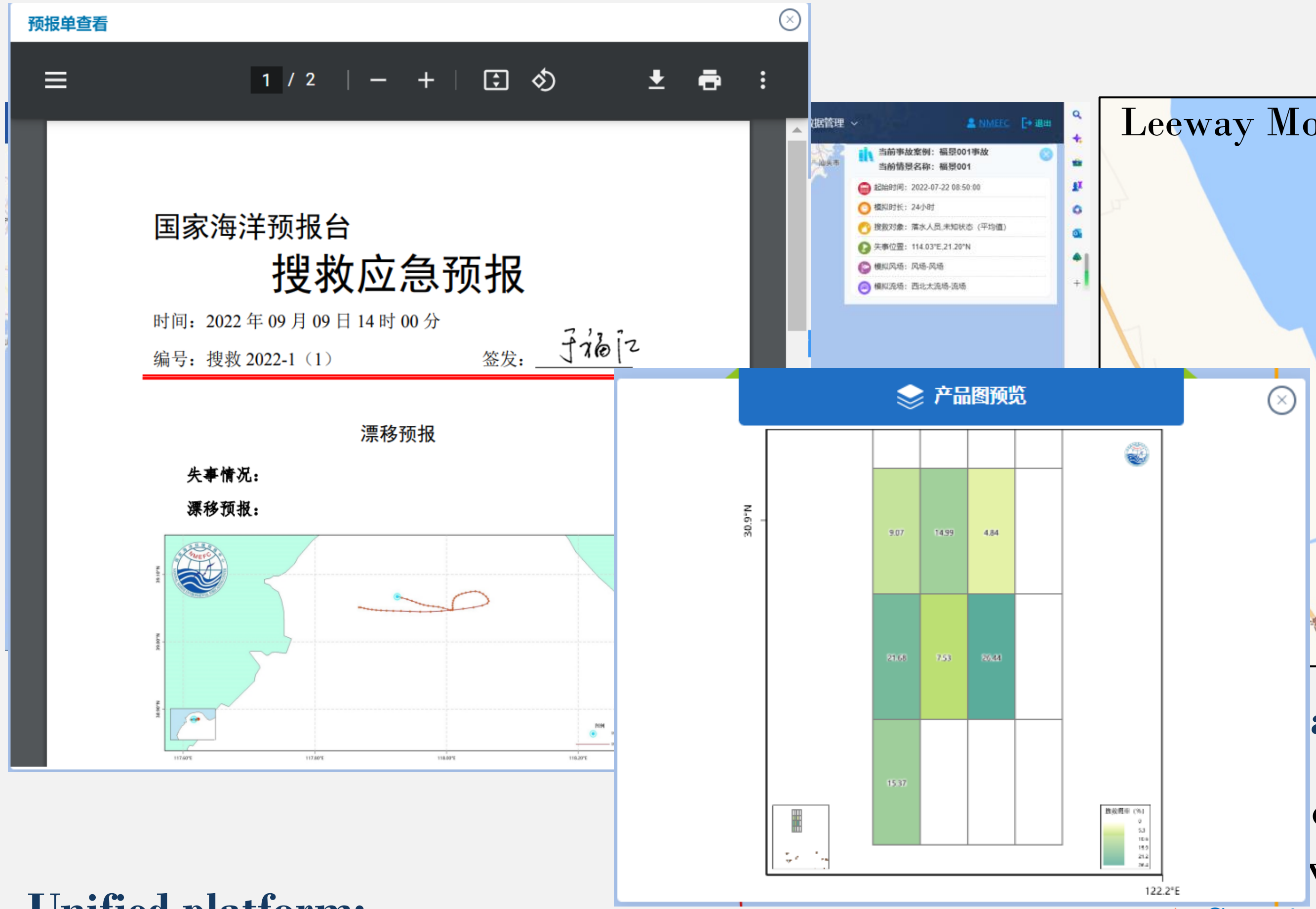
The modeled trajectory is basically consistent with the measured trajectory, and the **distance error within the first 40 hours is less than 0.5 km.** The results show that the model is reliable

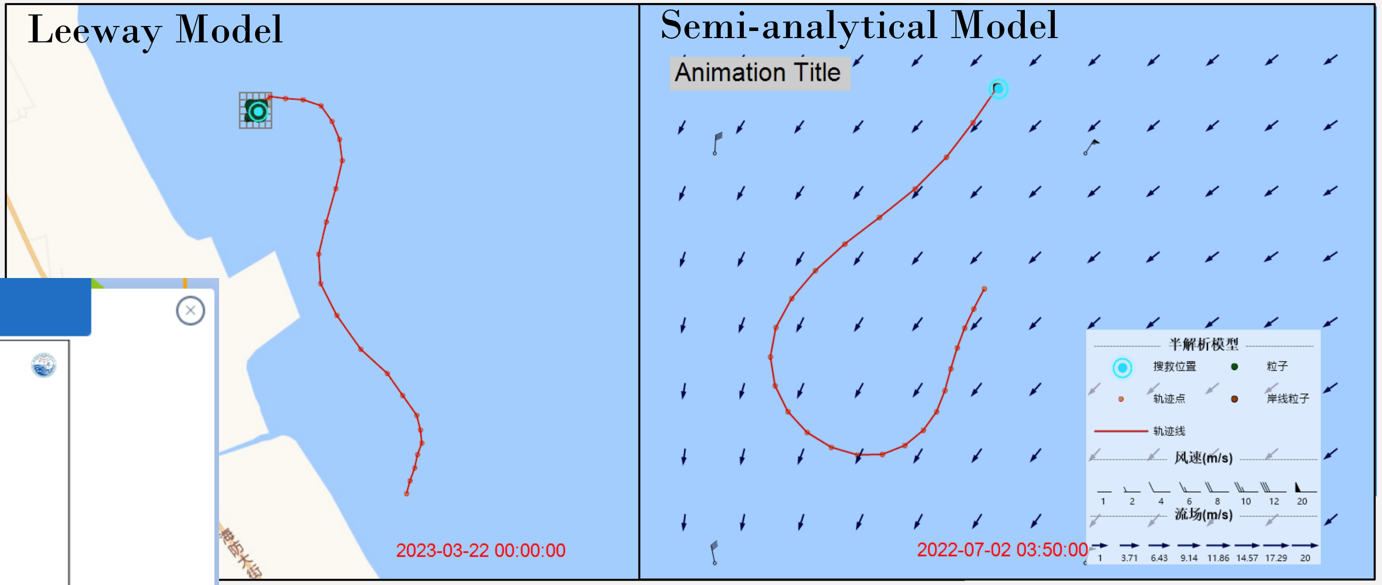
03

Search and Rescue Emergency Forecasting



3.1 Search and rescue (SAR) emergency forecasting platform





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.

al improvements:

characteristic drift coefficient database for typical vessels in China was constructed

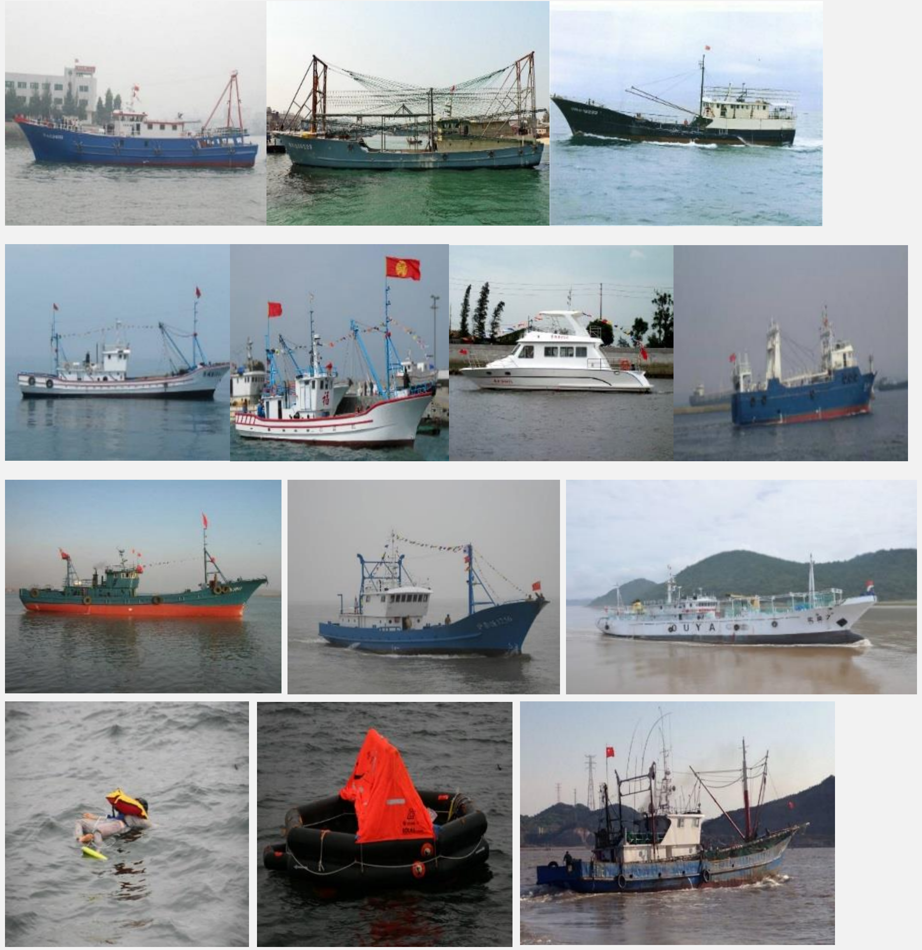
★ **Semi-analytical model** was developed with expanded marine target coefficient database

★ 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

3.2 Improvements in the SAR model

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



Typical fishing vessels in China

Open sea tests

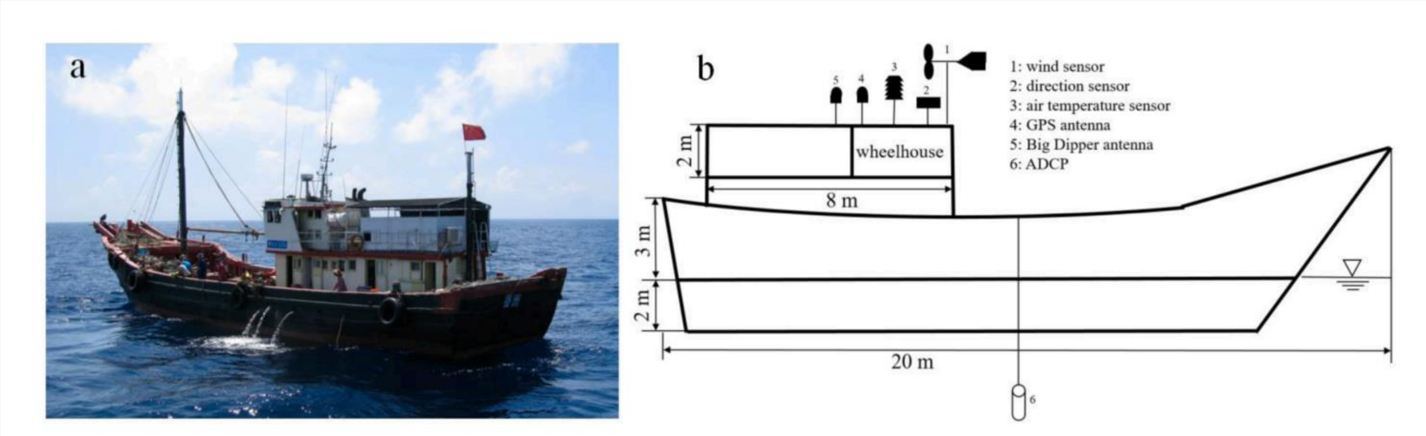
Enriched marine target coefficient database that applicable to the China's maritime search and rescue:
Up to 93 leeway target types including life rafts, small craft, and typical commercial fishing vessels.

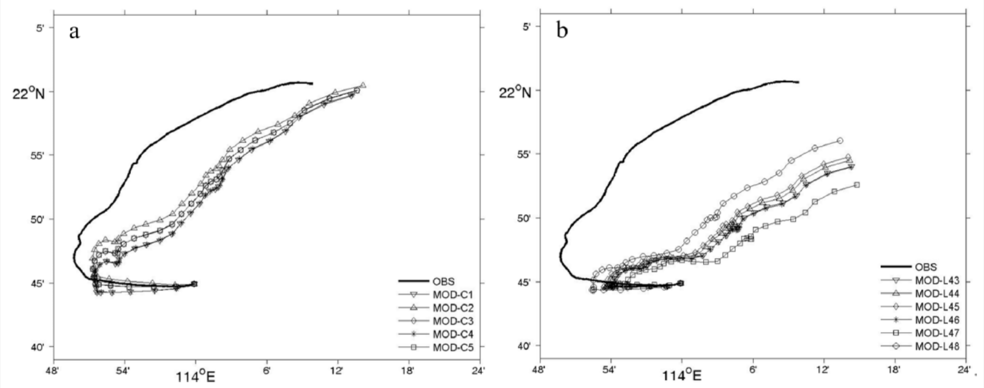
3.2 Improvements in the SAR model

» 2. Enrich Leeway drift coefficient database

A case study on a 20m length fishing vessel was conducted to determine the wind-induced drift characteristic through leeway speed, downwind component of leeway (DWL), crosswind component of leeway (CWL) coefficients, and explore how the fishing vessels drift in the surface water with the wind effect.

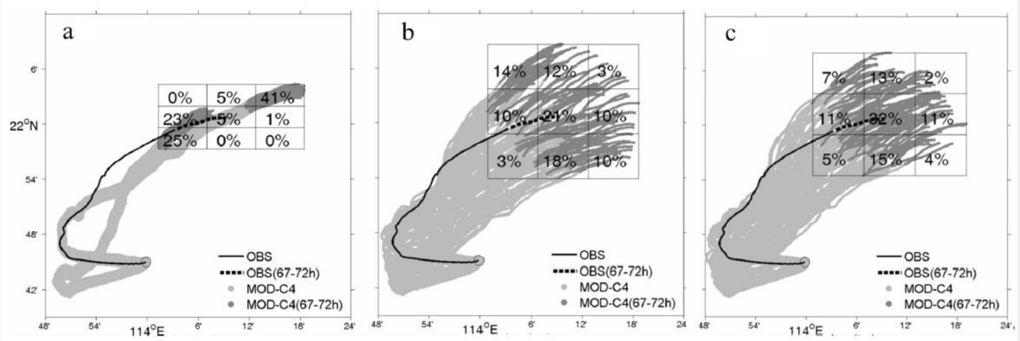
DWL			+CWL			-CWL		
Slope%	Ycm/s	$S_{y/x}$ cm/s	Slope%	Ycm/s	$S_{y/x}$ cm/s	Slope%	Ycm/s	$S_{y/x}$ cm/s
3.08	5.89	7.24	1.34	3.61	6.21	0.19	-6.83	3.92





Comparison between the observed drift trajectory and the mean simulated drift trajectory based on different coefficients

- The modeled drift trajectories calculated using new coefficients is more consistent with the actual situation
- The forecast search area and the probability distribution of drift particles are sensitive to characteristics of CWL sign change: the change condition and the frequencies of sign change, respectively.



The simulated particle drift distribution range and probability distribution of drift particles with frequency of CWL sign change as 0 (a), 4%/h(b) and 5.6%/h(c)

Sujing Meng, Wei Lu, Yun Li, Hui Wang, Lifang Jiang. (2021). A study on the leeway drift characteristic of a typical fishing vessel common in the Northern South China Sea, *Applied Ocean Research*, 109.

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 $\quad \vec{F}_w = \frac{1}{2}\rho_w C_w A_w |\vec{V}_{rw}|\vec{V}_{rw}$

wind drag $\quad \vec{F}_a = \frac{1}{2}\rho_a C_a A_a |\vec{V}_{ra}|\vec{V}_{ra}$

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

$\vec{V}_0$	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:

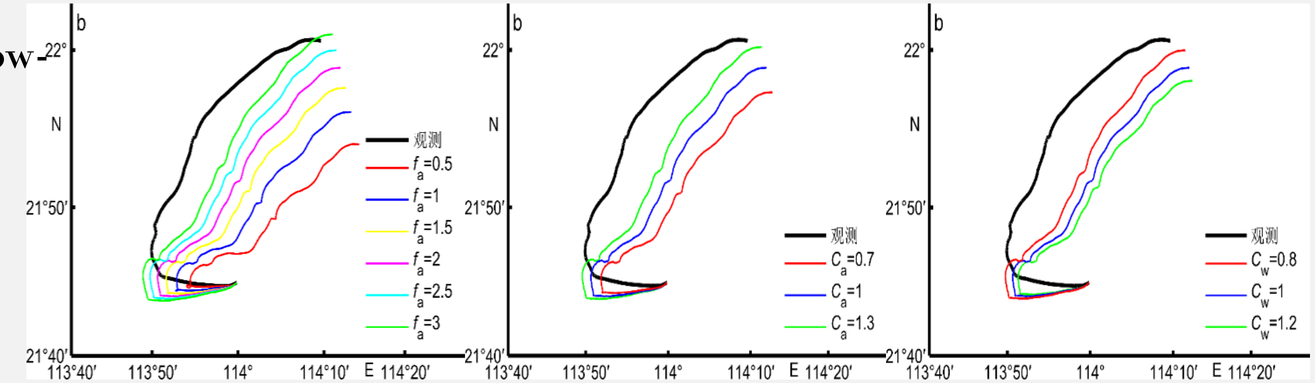
- RAB f_a : 0.5—3
- Wind drag C_a : 0.7—1.5
- Water drag C_w : 0.8—1.2

Semi-analytical Model wind slopes:

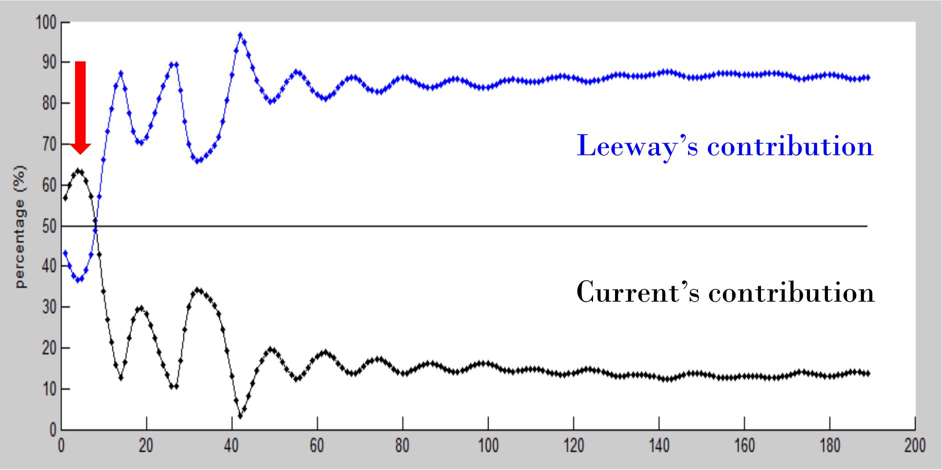
1.88%—7.76%

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

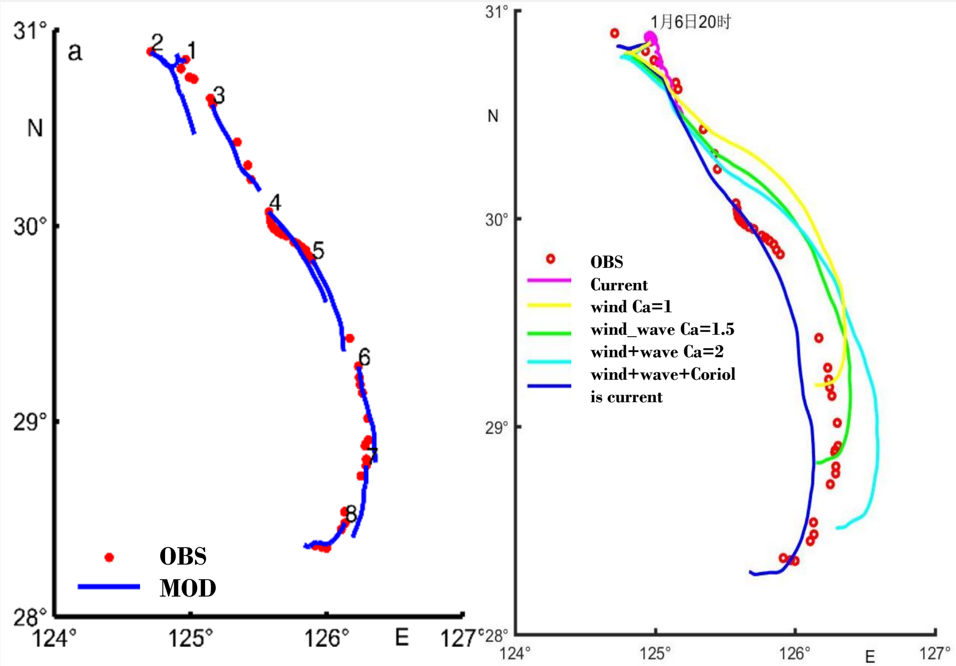
3.2 Improvements in the SAR model

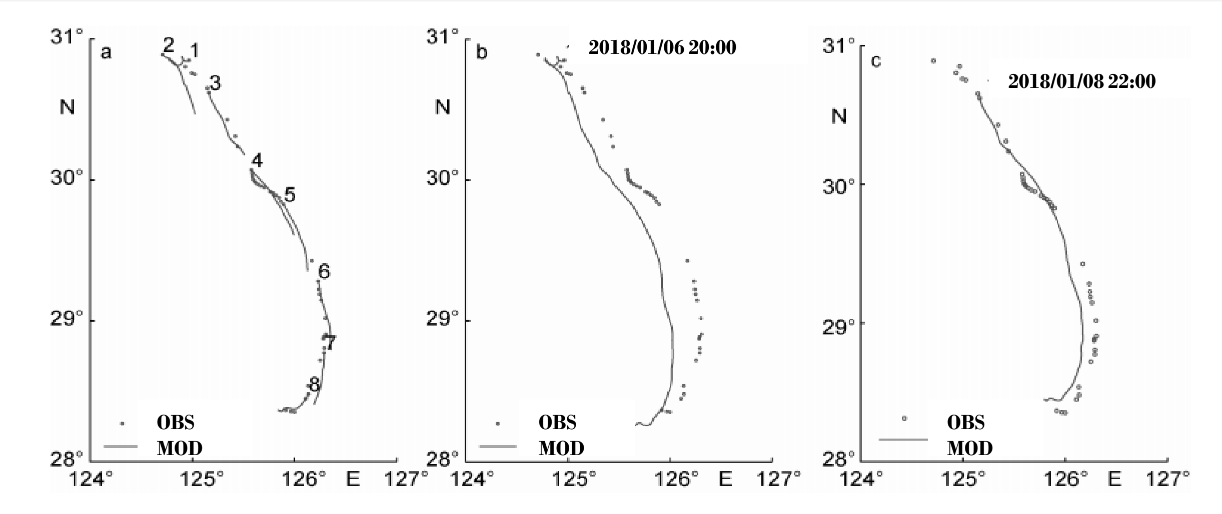
The model was applied in the drift trajectory prediction of "Sanchi". The average distance errors for the first 24 hours are as follows:

- **5.4 km** for the semi-analytical model
- 11.7 km for the leeway model
- 8.9 km for the leeway model result with manual correction

➤ The forecasting accuracy improved by **53%** compared to the classic Leeway Model, and **37%** compared to the Leeway modeled result with manual correction

➤ When the wind is stable, considering right deviation can improve the simulation performance



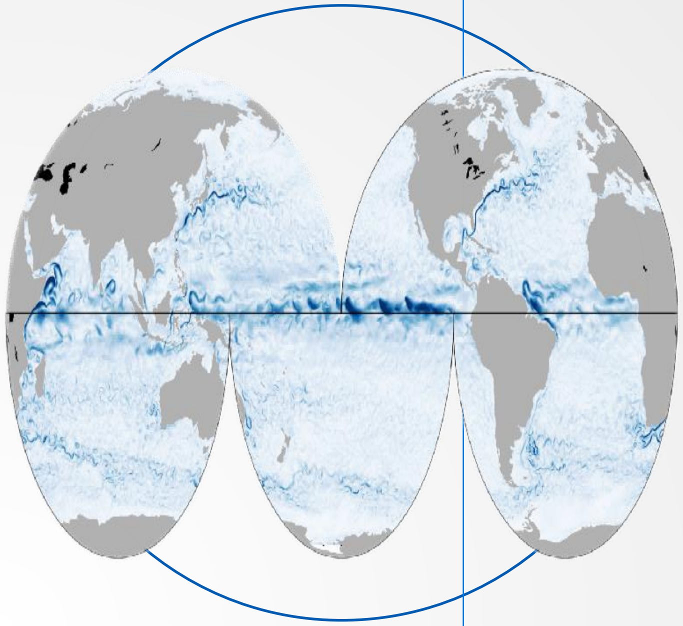


Simulated and observed drifting trajectories of the Sanchi Oil tanker considering Coriolis force:
(a) Rolling forecast (daily basis)
(b) Full range forecast
(c) Phased correction forecast

Leakage lightened the vessel

04

Applications in Maritime Emergency Response

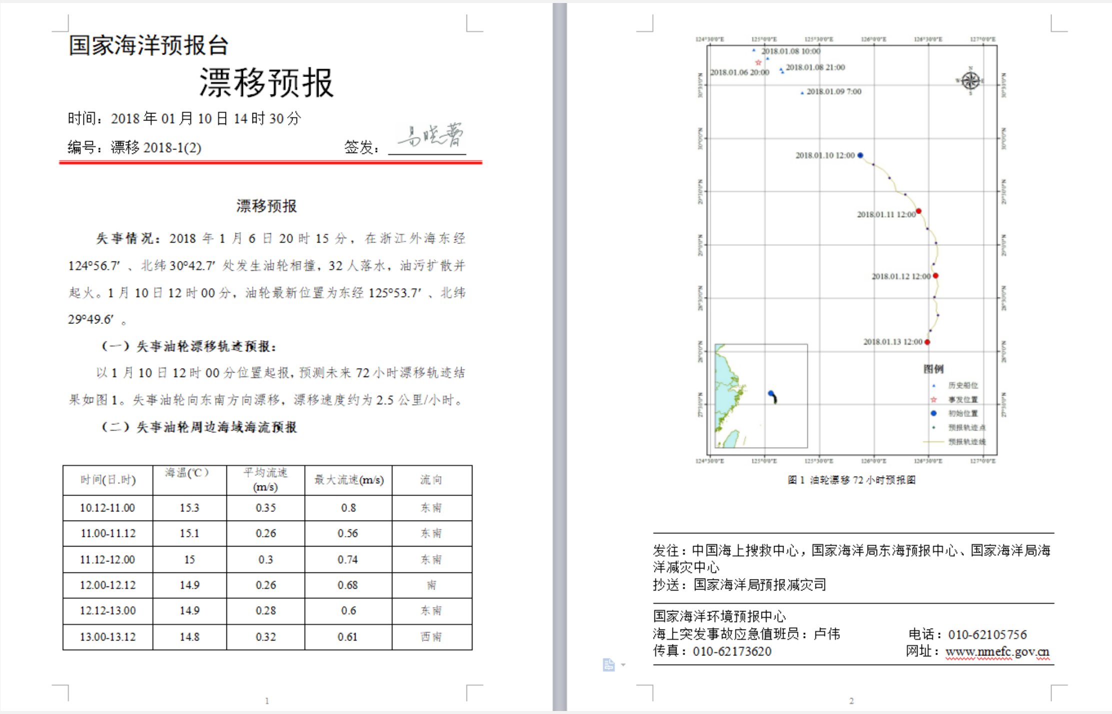


4.1 Applications in the tanker Sanchi oil spill emergency

» 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

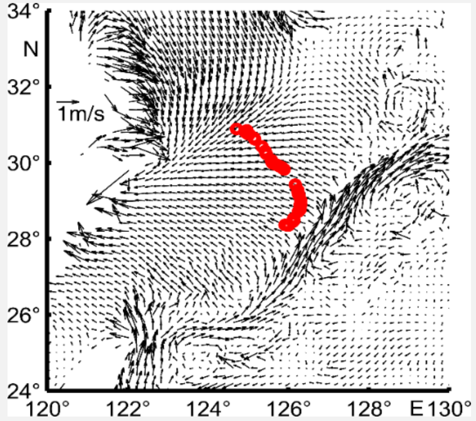
国家海洋环境预报中心

海上突发事故应急值班员：卢伟　　电话：010-62105756

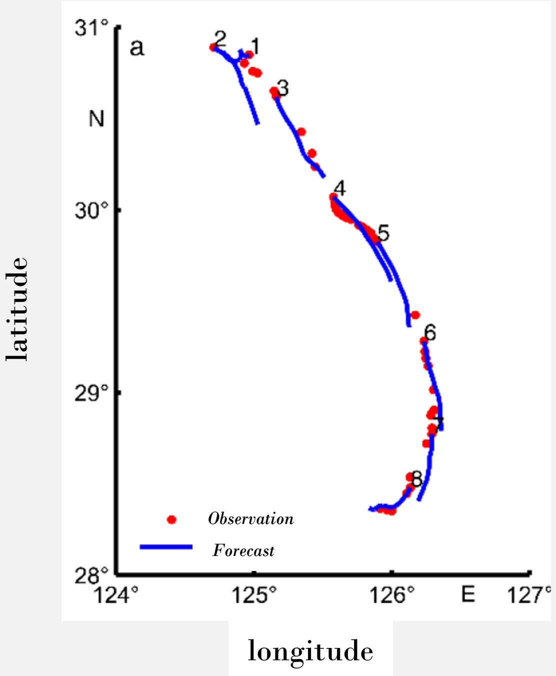
传真：010-62173620　　网址：www.nmefc.gov.cn

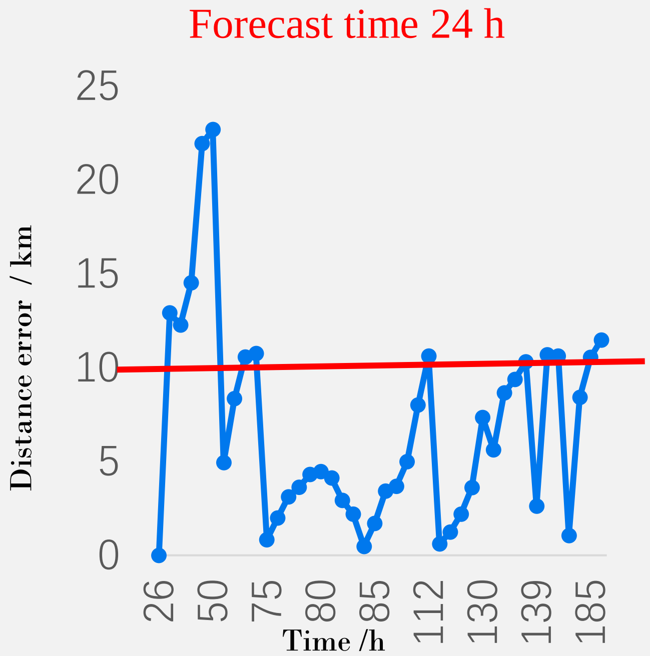
2

Sanchi caught fire after the collision



Observation trajectory

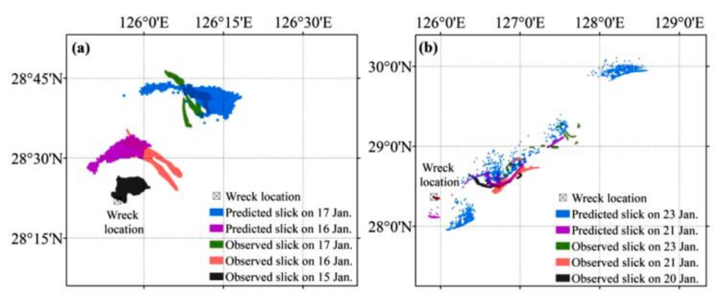




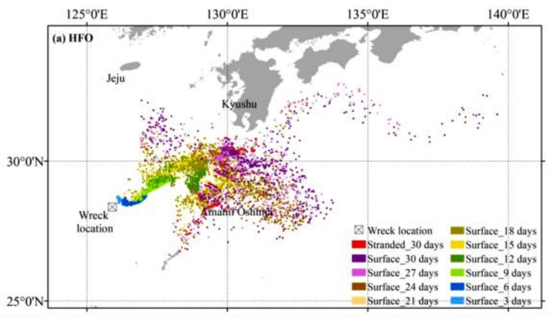
4.1 Applications in the tanker Sanchi oil spill emergency

- 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.

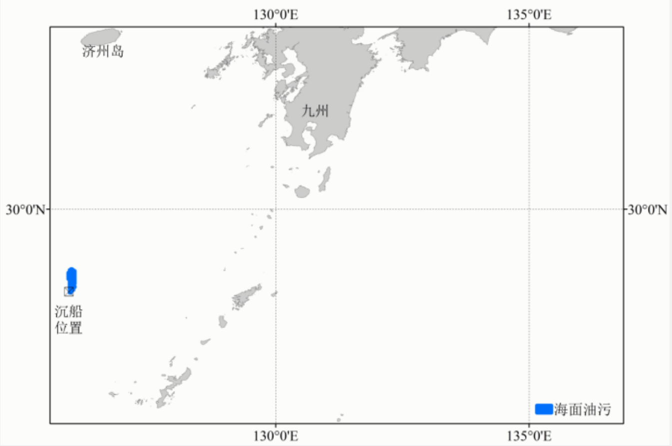
The forecasting conclusions have successfully **supported the decision making** for the response of the *Sanchi* oil spill, as well as **environmental impact evaluation**.



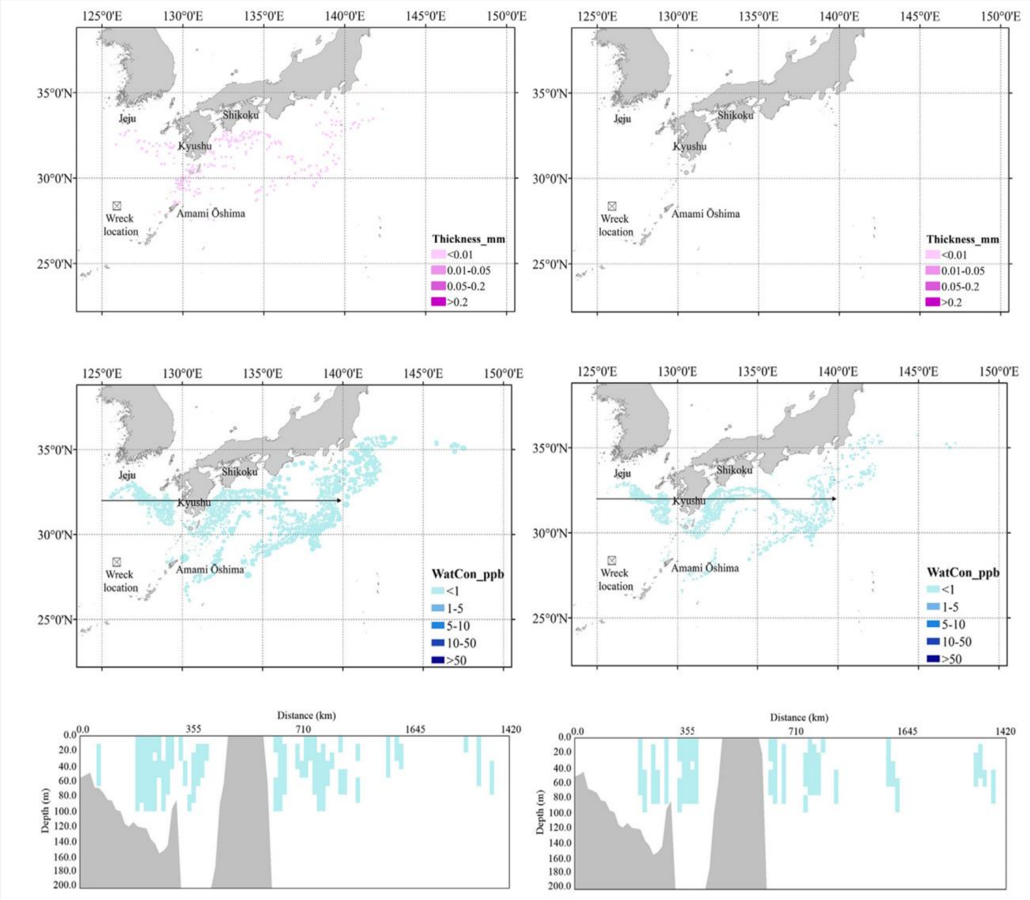
Validation of the forecasted surface slick against the satellite



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 Flight MH370

» 2. Assistance in the search for the Malaysia Airlines Flight MH370

The Malaysia Airlines Flight MH370 lost contact with 239 people on board at 1:20 on March 8, 2014 at 6°55′15″N, 103°34′43″E. Debris from MH370 was found on Réunion Island, France on July 29, 2015. The “Donghai Rescue 101” were sent to the eastern part of the Southern Indian Ocean for a search mission in February 2016.

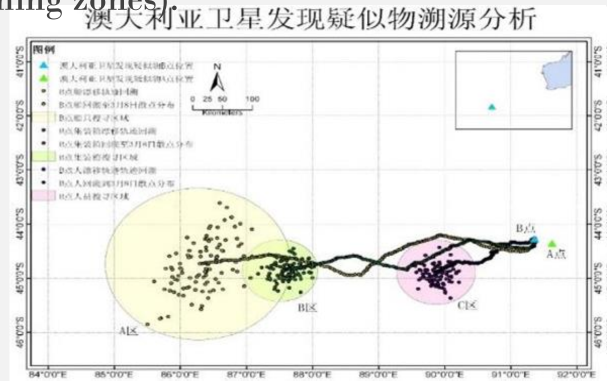
1. To simulate the possible origins of debris

➢The NMEFC SAR model indicated that the drift of debris in the sixteen months (from March 2014 to July 2015) is likely to have been northward and then westward or directly westward starting from the northern search area.

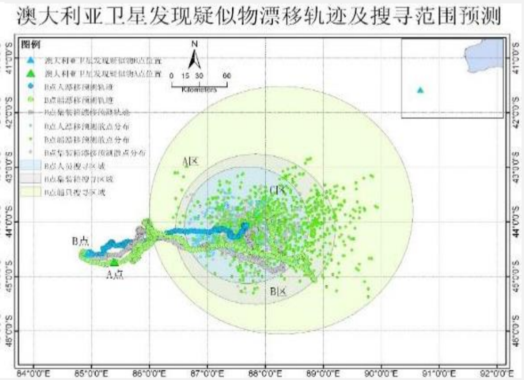
➢But starting from the southern accident site, debris likely drift eastwardly reaching to the western Australia.

2.To assess the planned underwater search area (in the red dashed area) published in Aug. 11 2015

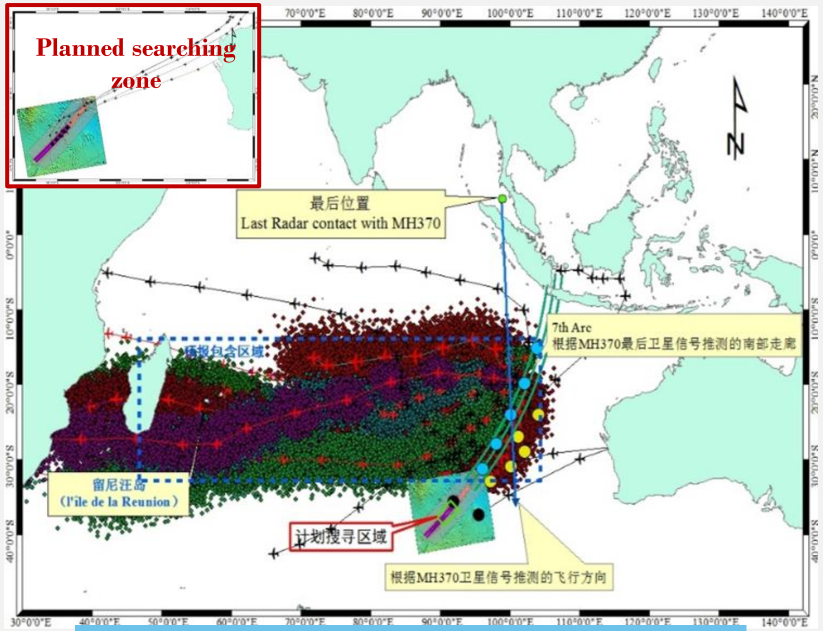
➢The debris found on La Réunion Island is less likely originated from regions covered by black points (previous planned searching zones).



Backtracking



Forecasting



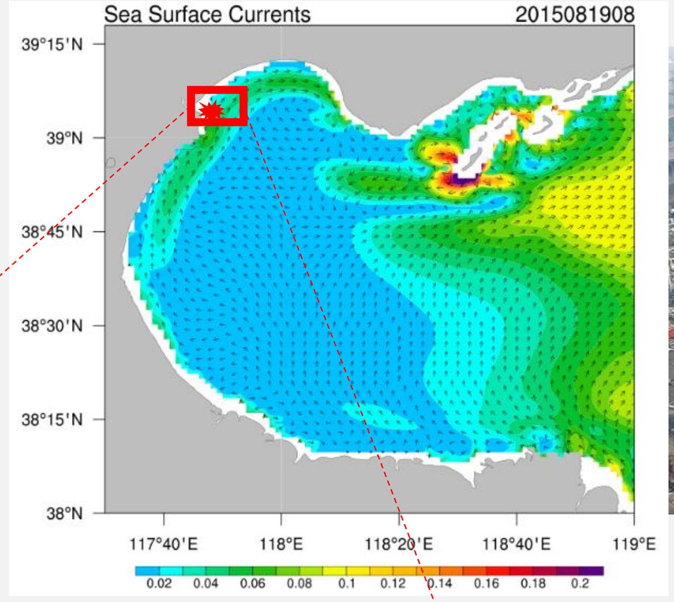
Possible simulation analysis of debris origin

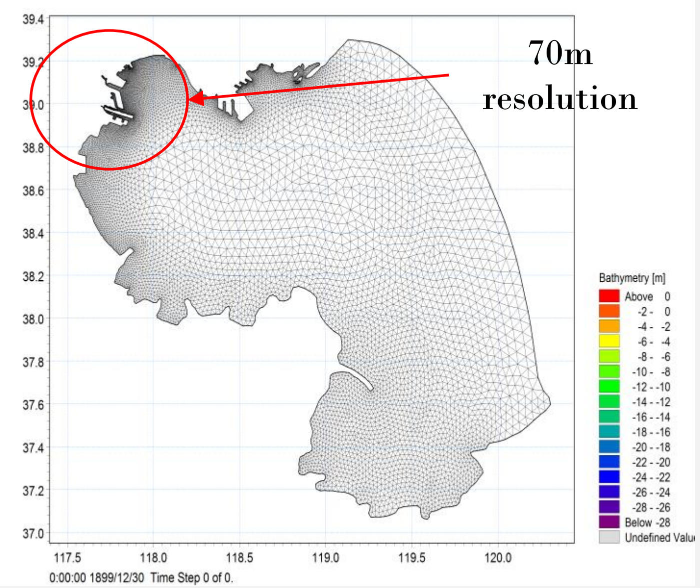
4.3 Applications in the transport and diffusion of hazardous chemicals

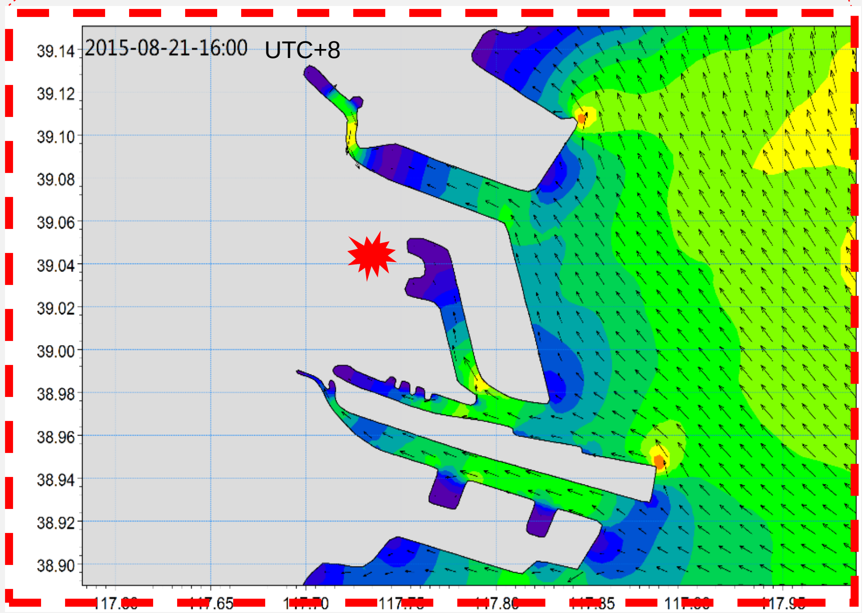
At 23:30 on August 12, 2015, the explosion came from a warehouse located at Tianjin Port, inside which are hazardous materials.

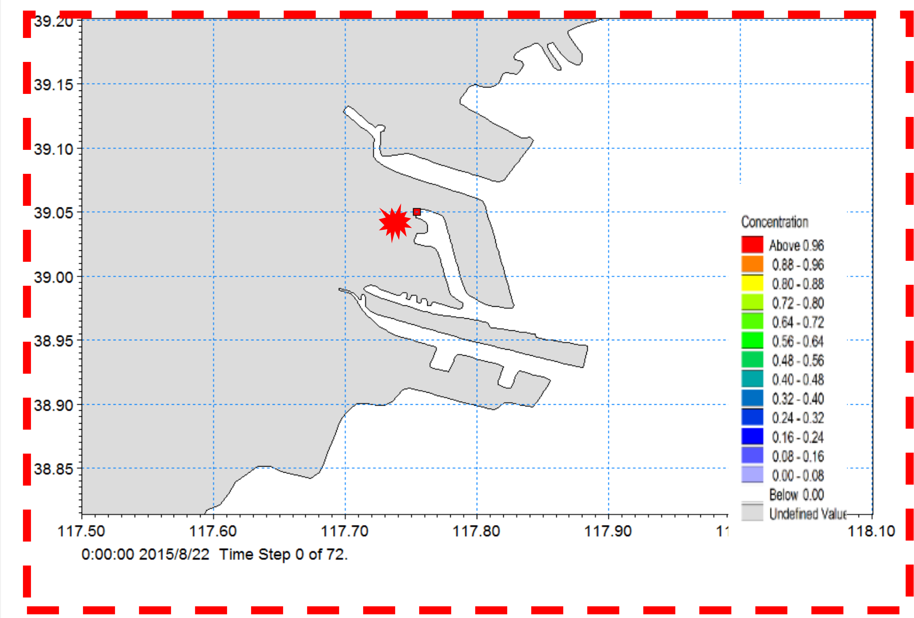
A high-resolution dispersal model of hazardous chemicals was established based on the operational forecasting system in the Bohai Sea (1/60°) with a horizontal resolution of 70m.

The model was established to simulate and predict the diffusion and arrival time of hazardous chemicals at the entrance. The model result provides support for decision-making process.



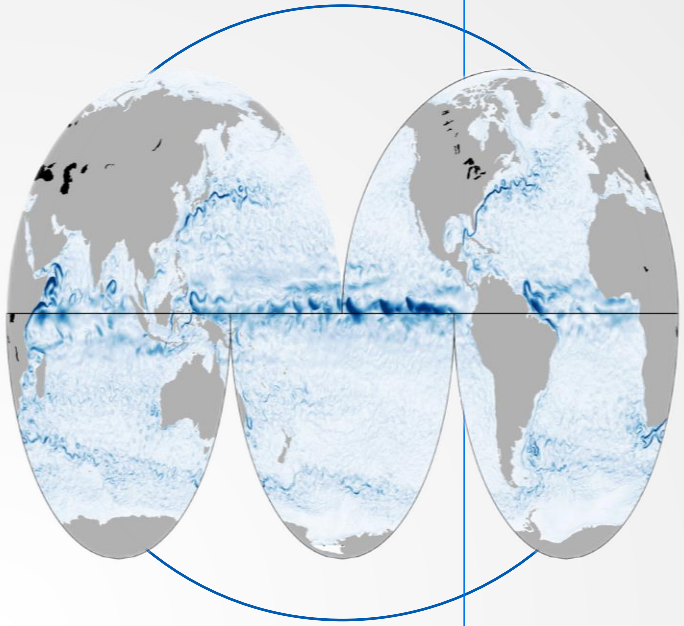






05

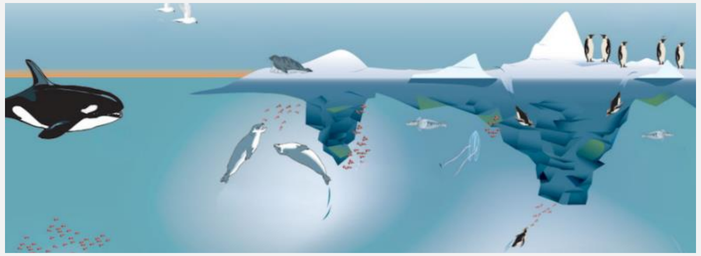
Future Works

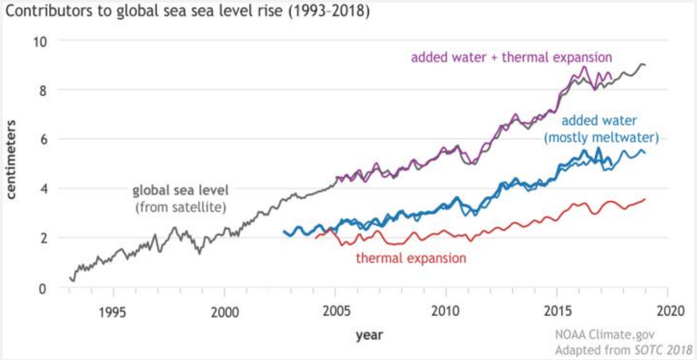


4 Provide maritime emergency forecast based on MaCOM

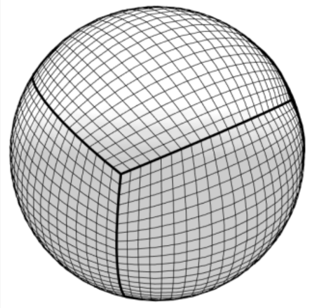
The Mass Conservation Ocean Model (MaCOM) model is a newly established and operated global circulation model, which adopts a complete physical framework. The key feature of which is mass conservation, enthalpy conservation, salt conservation, and based on pressure coordinates.

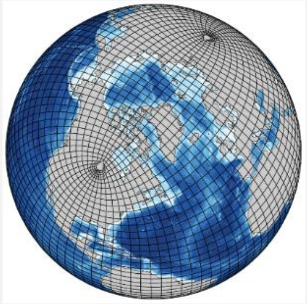
1 Mass conservation

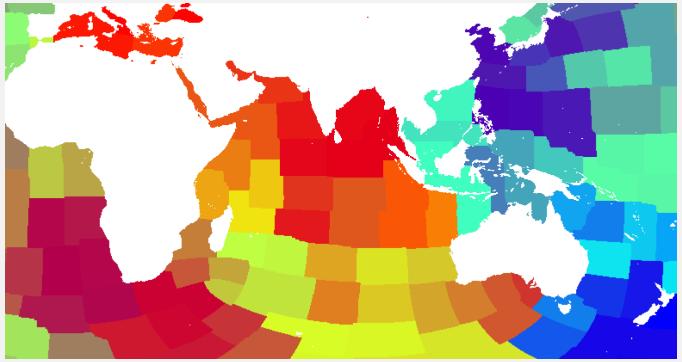




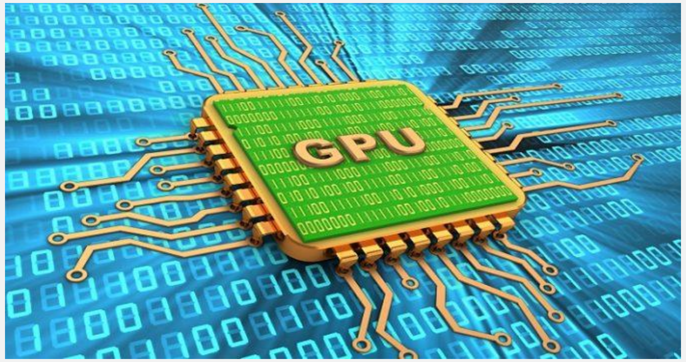
2 Flexible grid support







3 Heterogeneous computing



4 Provide maritime emergency forecast based on MaCOM

Multiple models are needed for different spatial scales and different environmental elements

CPU parallel

Mass Conservation Ocean Model

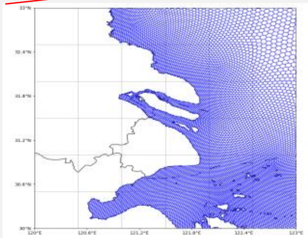
妈祖 aCOM

★ Coastal-Regional-Global multi-scale integrated

★ Circulation, wave, storm surge, and Tsunami multifactor coverage

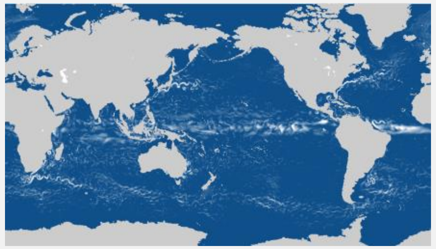
★ Multi-grids support without changing core codes

★ GPU parallel acceleration



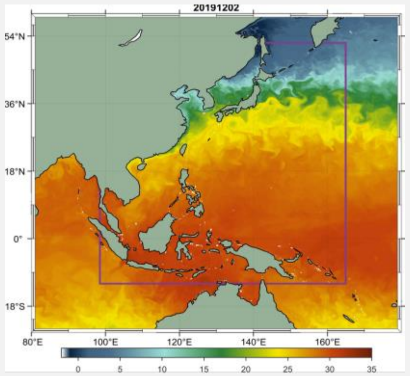
MaCOM Global

replace NEMO



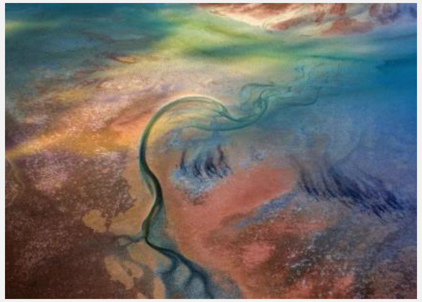
MaCOM Regional

replace ROMS



MaCOM Coastal

replace FVCOM



THANKS

Thank you for listening