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The SCS Guangdong-Hongkong-Macao Greater Bay Area Oceanographic Analysis and Forecasting System

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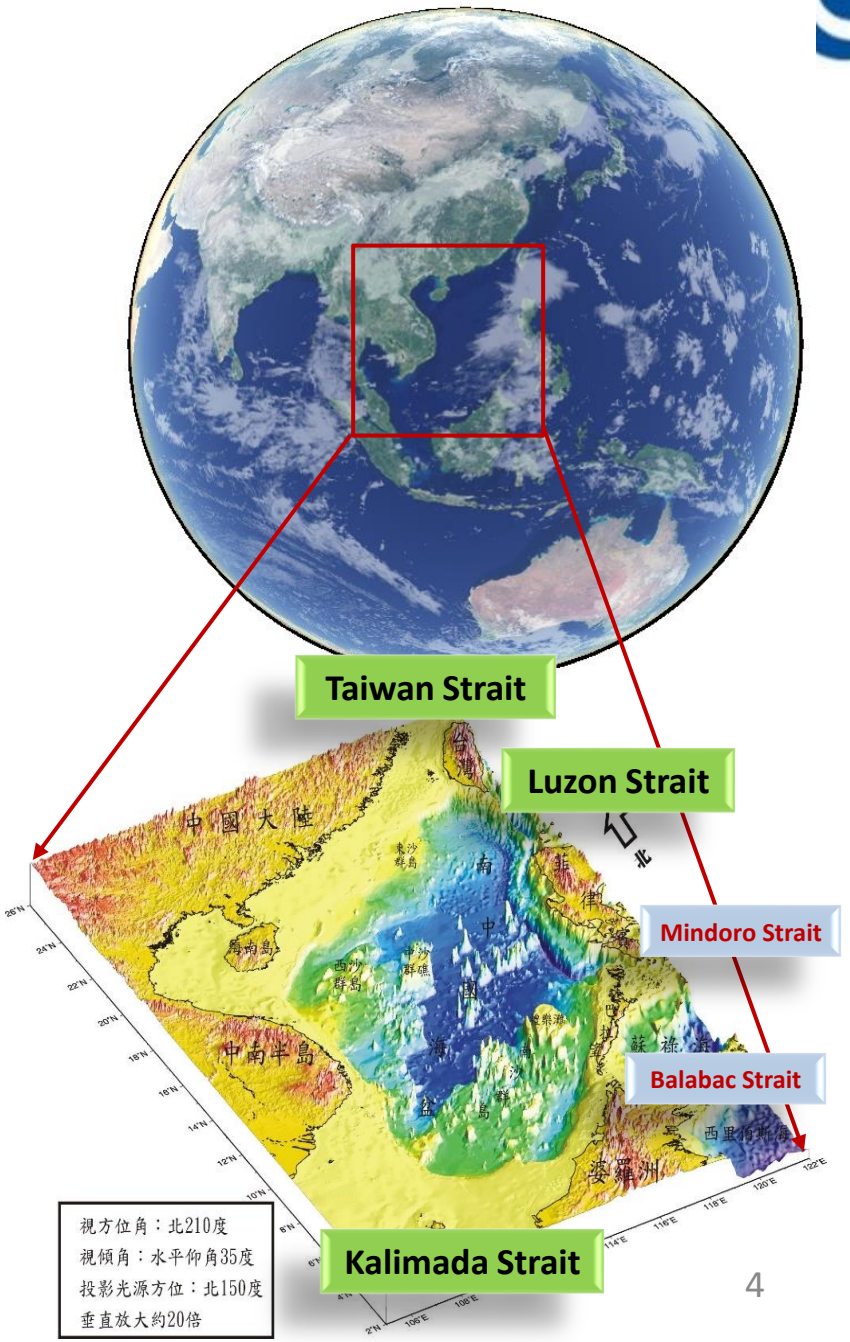
- Introduction
- SCS OFS
- GHM-GBA OFS
- Applications and future work

Contents

1.1 Introduction to the SCS

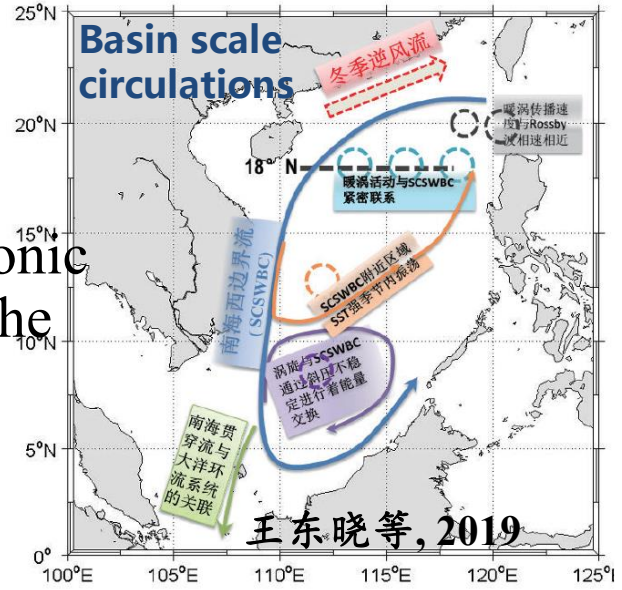
- The SCS is semi-enclosed marginal sea, connected with the adjacent seas through several straits.
- The total area is about 3.5 million square kilometers, with the mean depth 1212 m, and the maximum depth 5559 m
- The bathymetry is extremely complex, with numerous islands, reefs, shoals or reefs distributed



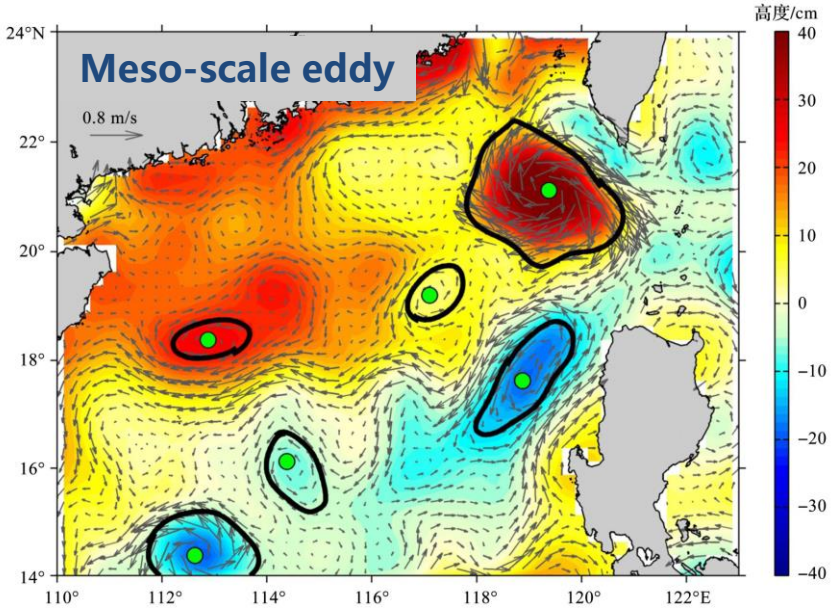
1.1 Introduction to the SCS

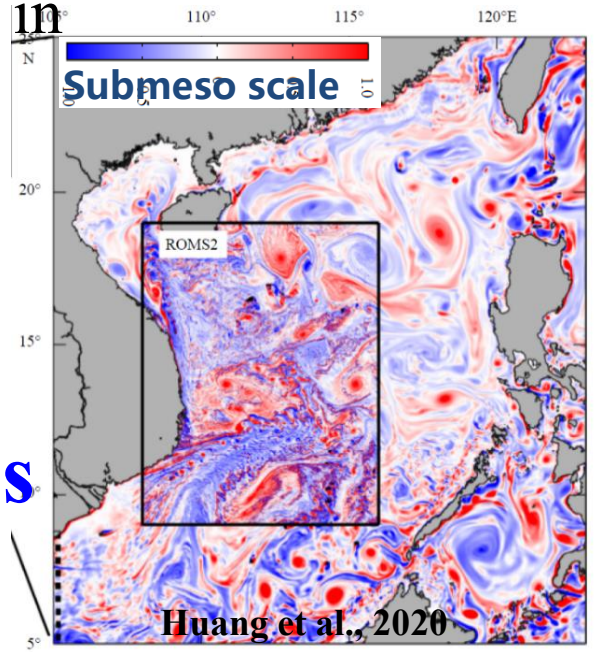
- **Basin-scale circulations**
  - ✓ Cyclonic in winter, anti-cyclonic in summer
  - ✓ Persistent cyclonic in the NSCS, Cyclonic in winter, anti-cyclonic in summer in the SSCS
- **Mesoscale eddy** activities are obvious and abundant.
- **Submesoscale activities** are ubiquitous in the SCS, can induce strong vertical advection.
- **Oceanic fronts** have been detected as Kuroshio fronts, upwelling fronts, and river plume fronts.

☐ **multiscale oceanic structures prevailing in the SCS**

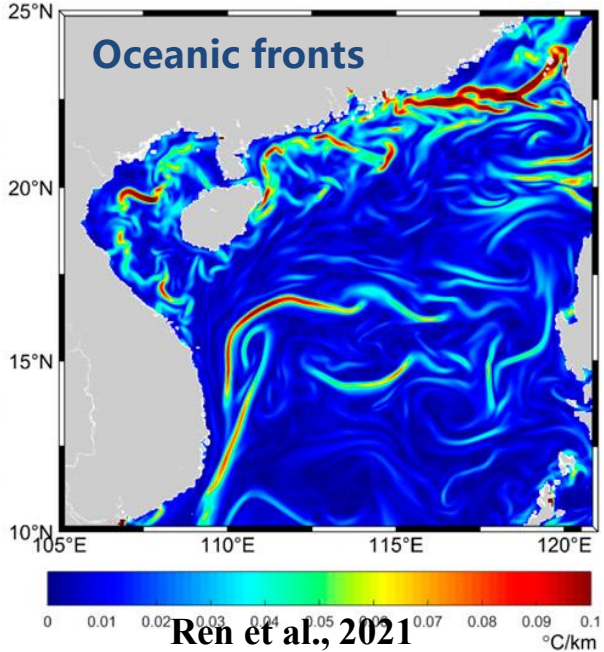


王东晓等, 2019





Huang et al., 2020

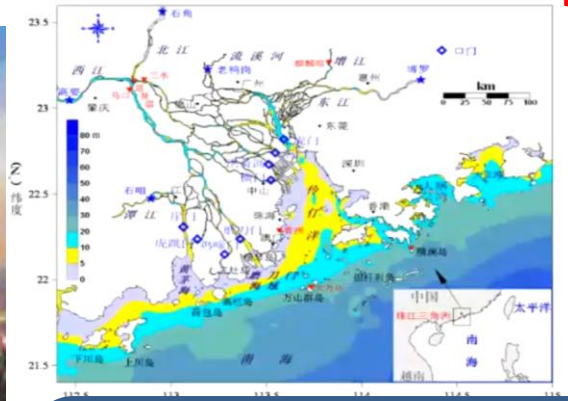


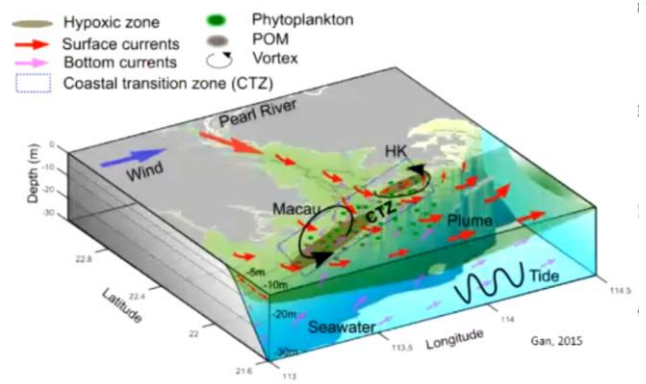
Ren et al., 2021

1.2 Introduction to the GBA

Guangdong-HongKong-Macao Great Bay Area

It is one of the regions with the highest degree of openness and the strongest economic vitality in China. It is the core growth pole of china’s economic development, accounting for 12% of China’s GDP.





Unique Sea-Land-Air-ecological interaction area

5 rivers—Dongjiang、Liuxi、Beijiang、Xijiang、Tanjiang

8 river mouths—Humen、Jiaomen、Hongqili、Hengmen、Modaomen、Jitimen、Hutiaomen、Yamen

800+ islands—east to Dongsha，facing to Luzon Strait and West Pacific

- Frequent human activities
- Intensified development and utilization in coastal zones.

2017 Hato storm surge

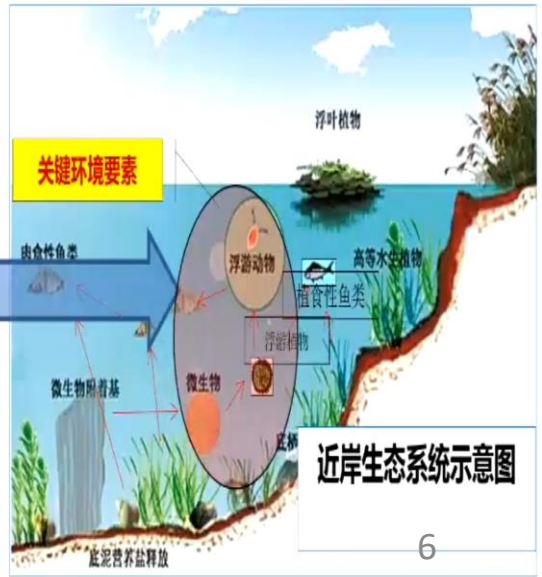
GHM is one of the regions most severely affected by marine disasters, such as the typhoon Hato in 2017.

Pearl River Discharge

Human activities

Natural environments

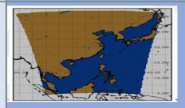
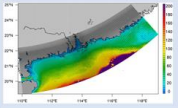
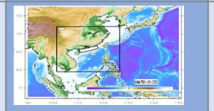
Ocean dynamics



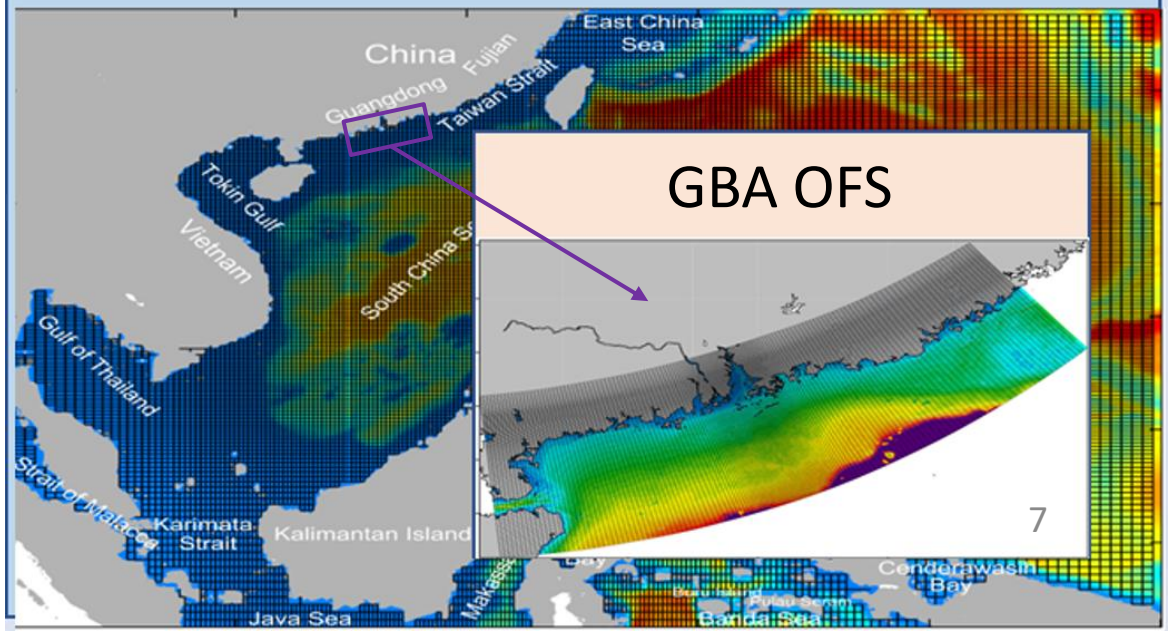
1.3 Objectives and Solutions

How to efficiently and reasonably simulate, reproduce, and predict three-dimensional ocean dynamic environments of the SCS-GBA with multi-scale dynamic characteristics?

Ocean Atmospheric Numerical Forecasting System

	台风预报系统	大气预报系统	海流预报系统	海浪预报系统	风暴潮预报系统
数值	WRF	WRF	ROMS	SWAN	SLOSH、ROMS
预报区域					
分辨率/垂直层	4km/41层	36 km、12 km和4 km/41层	250m~1km/30层	250m~1km	100m~250m~1km
预报频次及时效	18/06UTC，72h	18UTC，120h	12UTC，120h	12UTC，120h	72h，120h
输出间隔	1h	1h	1h	1h	1h
输出要素	降水、风向、风速、台风路径、强度等	气温、气压、湿度、风，降水	海温、盐度、海流、水位	波高、周期、波向	水位

SCS Oceanographic Forecasting System



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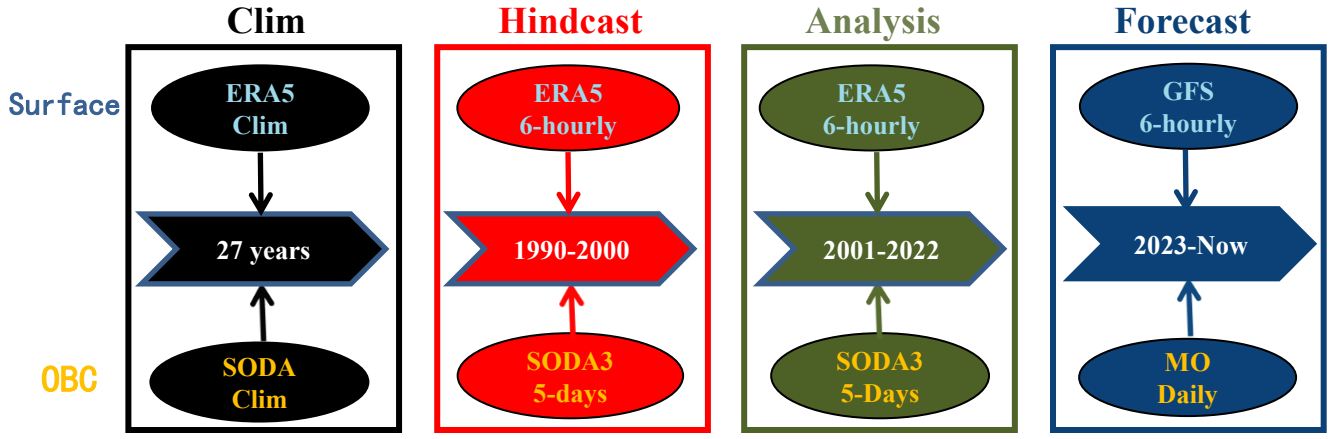
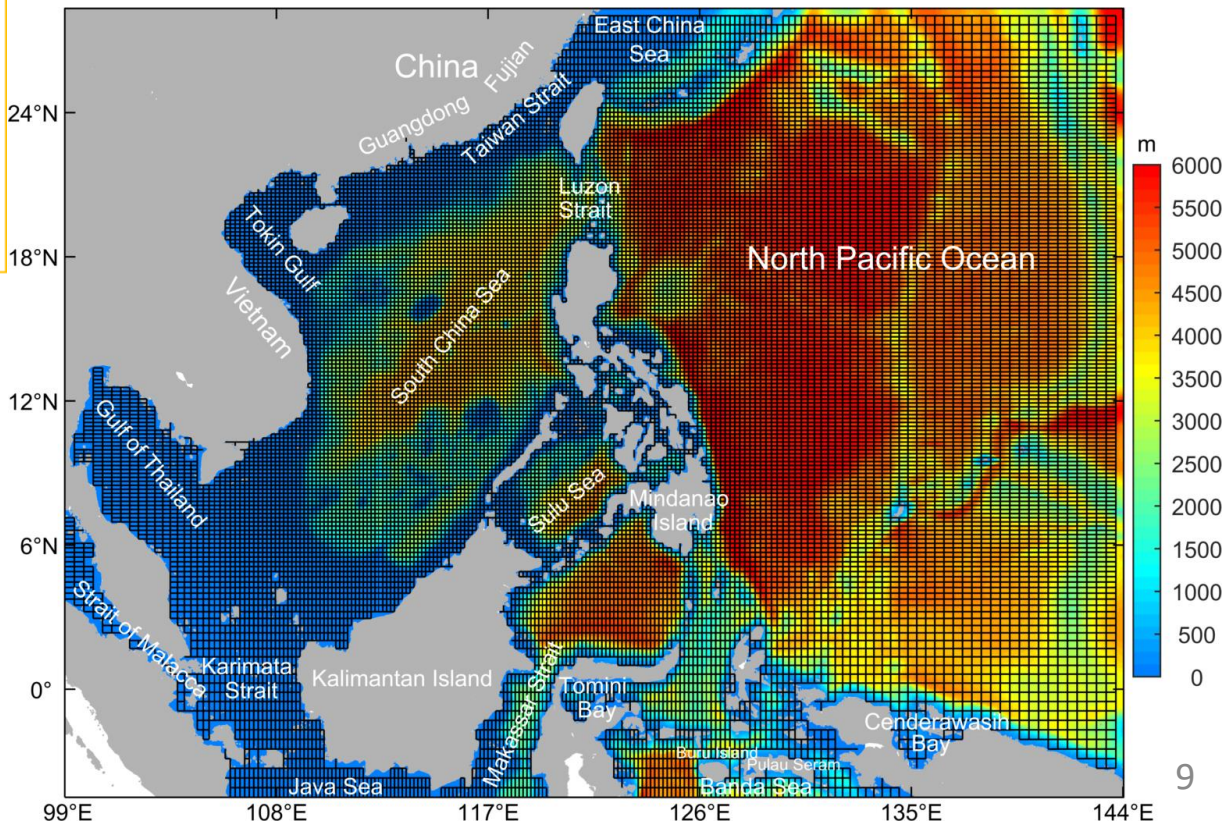
2.1 Model settings

- Based on ROMS **Version 4.0**
- **Domain**
  - ✓ -4.5°S~28.4°N, 99°~145°E
- **Horizontal Resolution**
  - ✓ 1/12°～1/30°, Grid NO.: 985×793
- **Vertical Resolution**
  - ✓ 50 Layers
- **Bathymetry data**
  - ✓ GEBCO（0.5′×0.5′）
- **Initial Conditions**
  - ✓ GDEMV3（0.25° ×0.25° ）

- **Forcings**
  - ✓ **Surface**: ERA5 6-hourly
  - ✓ **Open Boundary**:
    SODA3 5-days
    Mercator Ocean Daily
  - ✓ **River**: Pearl, Mekong monthly
- **Data Assimilations**
  - ✓ **Qcorrection:** AVHRR OISST
  - ✓ **EnOI:** AVISO SLA, OISST, Argo T/S profiles
- **Time step**
  - ✓ Ext. 5s; Internal: 180s

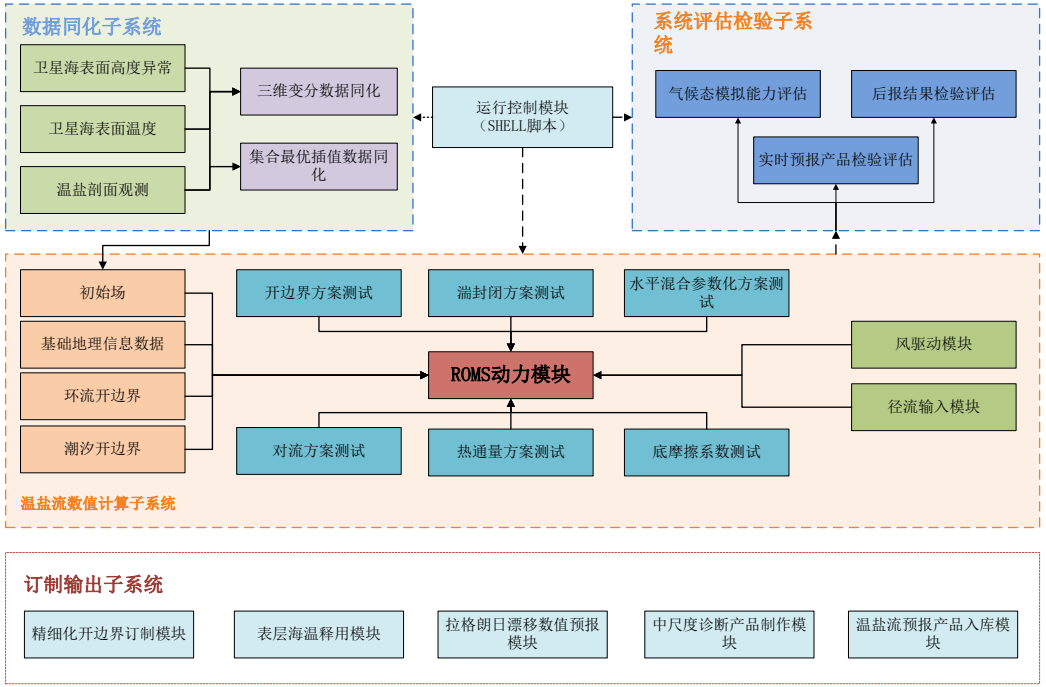
Model Run



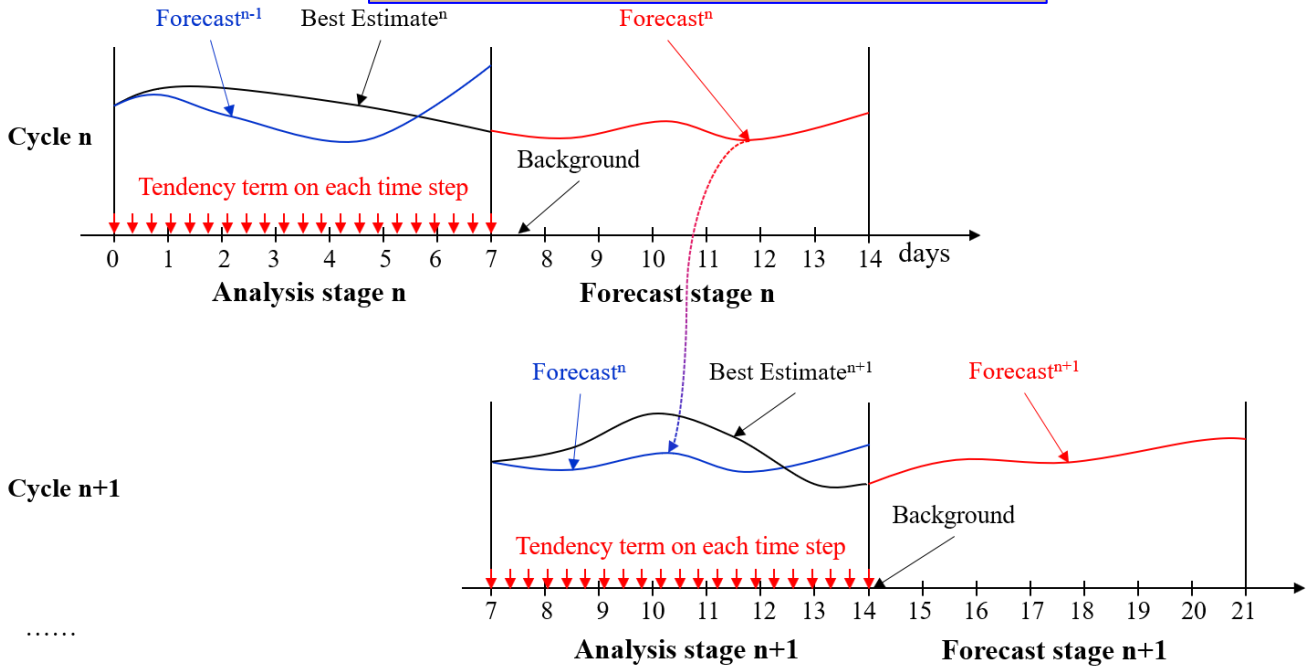


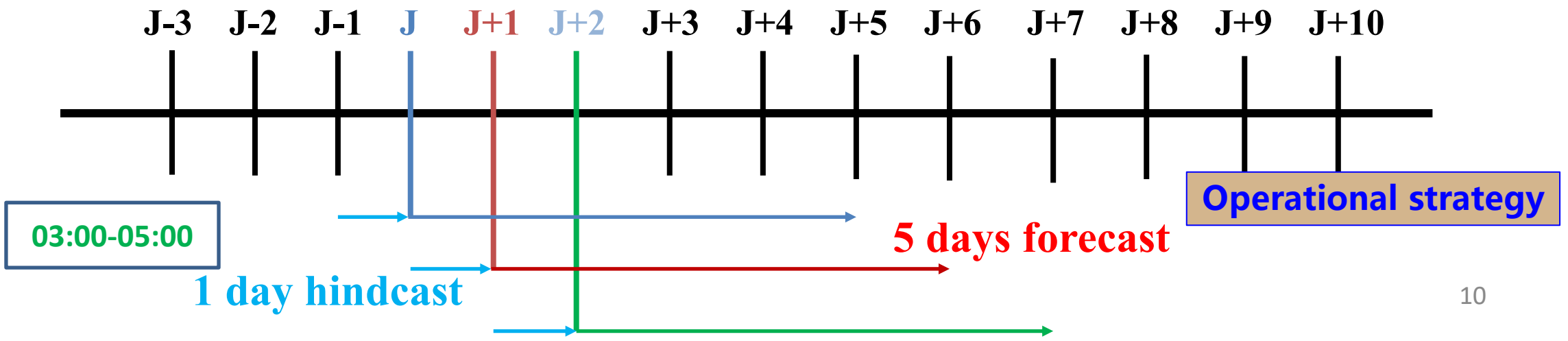
2.2 System running flow

System Components

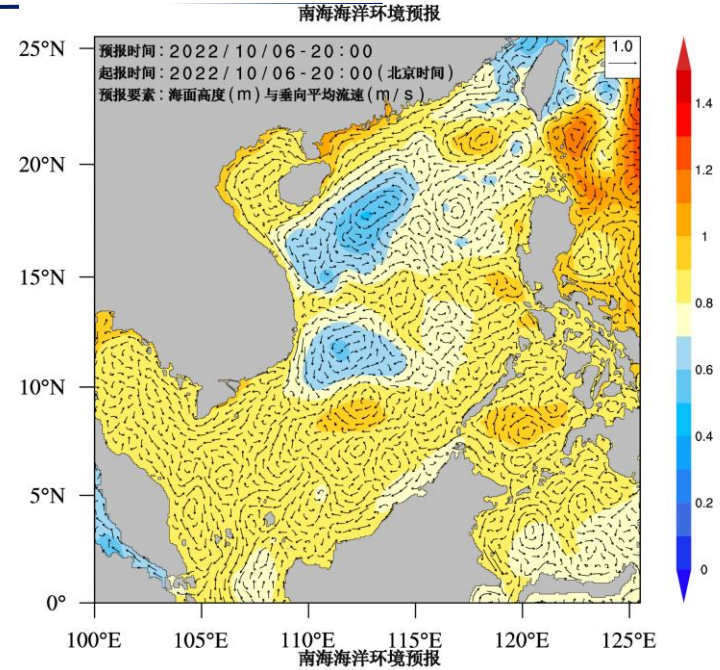


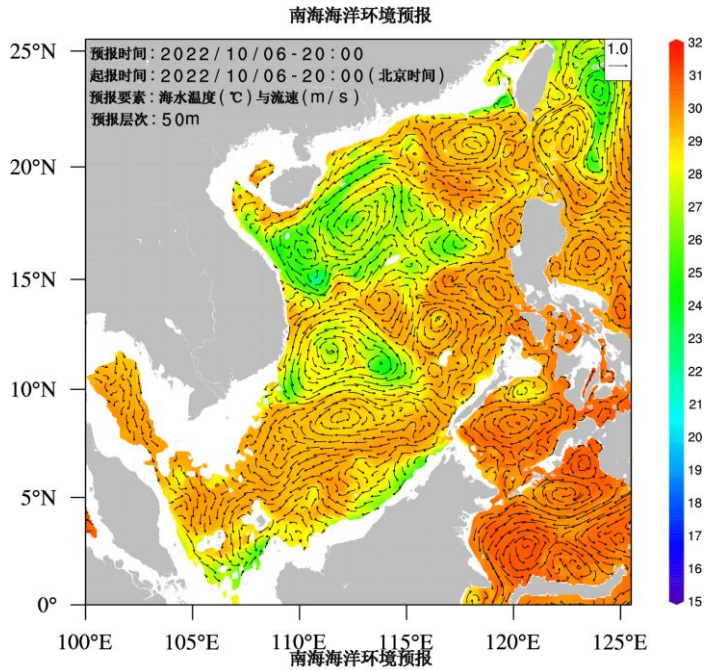
Multi-Source Ocean data Online Assimilation System

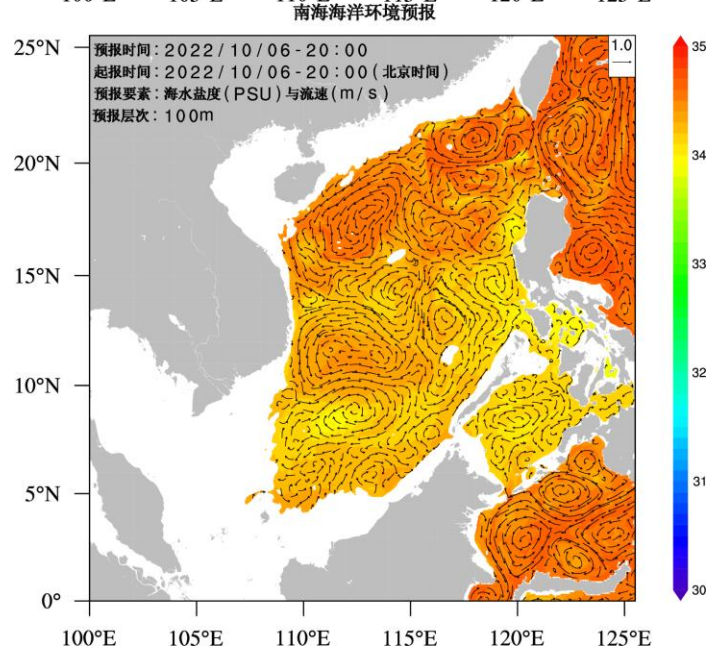


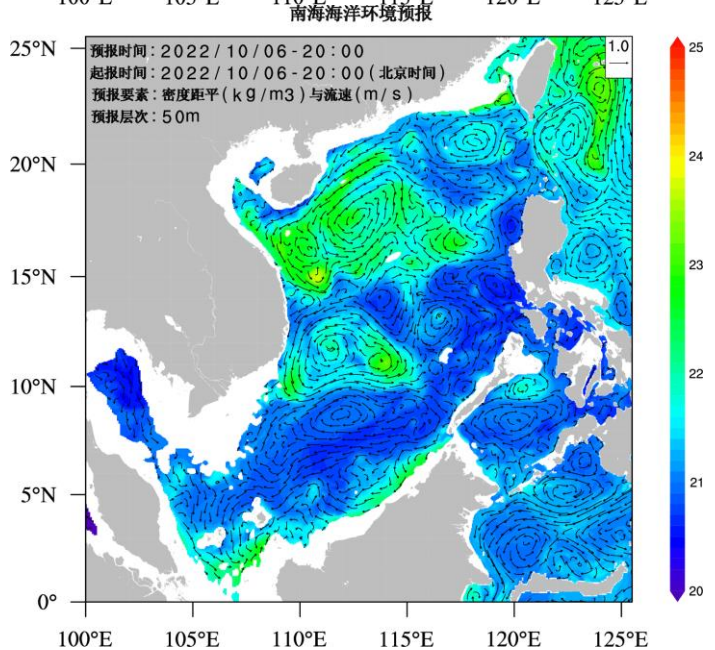


2.3 Forecasting Products





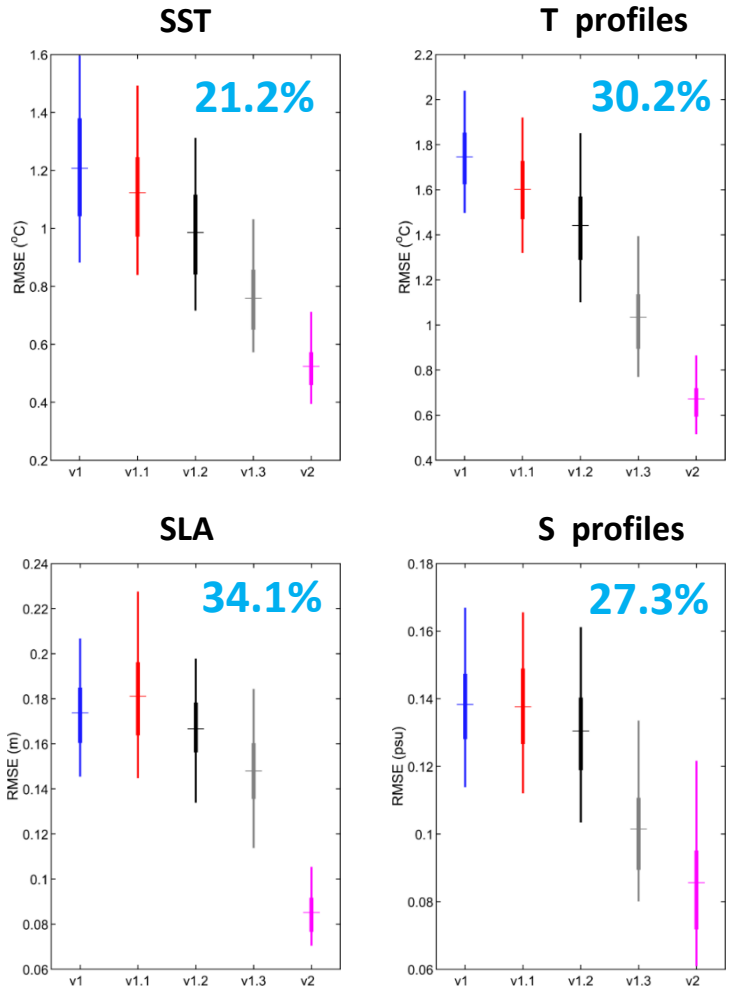




2.4 System improvements

versions	Settings update in detail
v1→v1.1	1) ROMS version changed from v3.5 to v4.0; 2) land–sea mask redistribution; 3) bathymetry substitution of ETOPO1 with GEBCO_2014; 4) initial temperature and salinity conditions changed from SODA2.2.4 to GDEMv3; 5) open boundary data changed from climatological monthly mean to monthly mean during 1990~2008 with SODA 2.2.4; 6) Sea surface atmospheric forcing changed from NCEP R2 to CFSR; 7) The dQ/dSST changed from constant to temporally and spatially varying values; 8) sea surface atmospheric forcing method changed from direct flux forcing to BulkFormula.
v1.1→v1.2	1) Open boundary data of SODA 2.2.4 monthly mean extended from 2008 to 2010; 2) the eastern lateral open boundary moved westward from 145° E to 144° E; 3) the observed SST data used for the net surface heat flux correction changed from MGDSST to AVHRR;
v1.2→v1.3	1) Mean sea level atmospheric pressure effect considered; 2) vertical layers increased from 36 to 50, the transform and stretching function changed; 3) Tracers advection discrete schemes changed from UCI to AAG; 4) OB data changed from SODA 2.2.4 monthly mean to SODA 3.3.1 and 3.3.2.
v1.3→v2	The MOOAS included.

RMSE variations

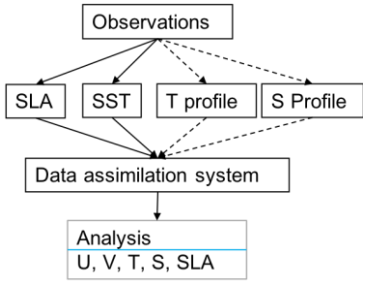


（Zhu et al., GMD, 2022）

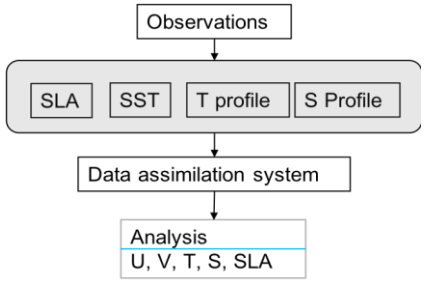
2.5 Improvements to EnOI

Multi-Source Ocean data Online Assimilation System

Assimilate multi-source data simultaneously



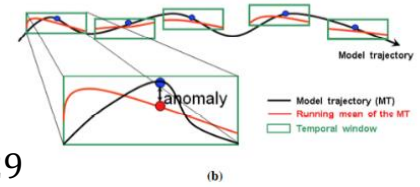
Old version



New version

Optimization of background error covariance estimation

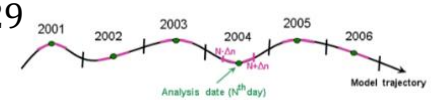
Old version $A'_i = A_i - mean(A_i)$



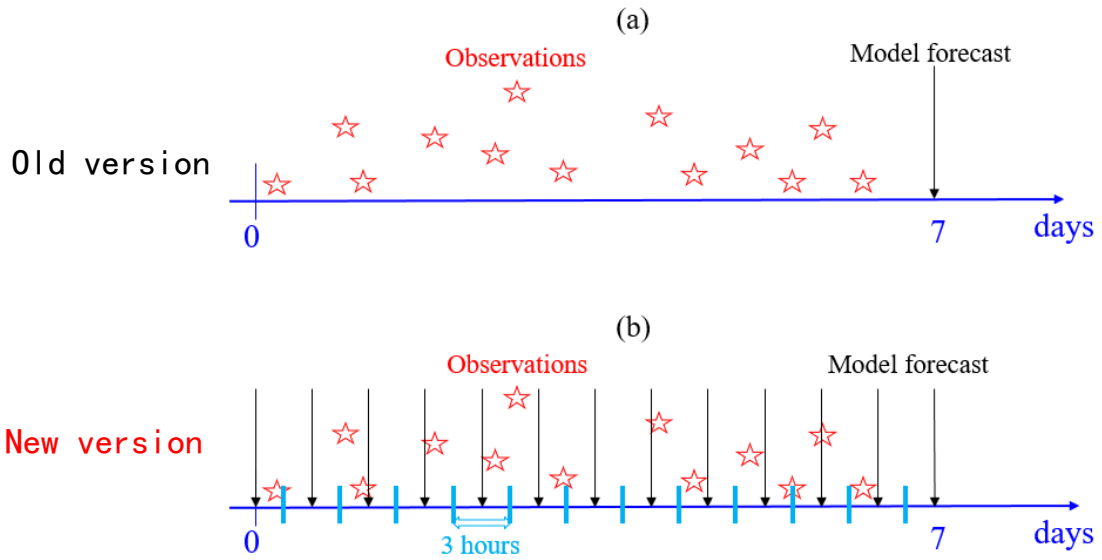
$\tilde{A} = Ha(A_i) \quad i = 1, \ldots, 29$

New version $A'_i = A_i - \tilde{A} \quad i = 1, \ldots, 29$

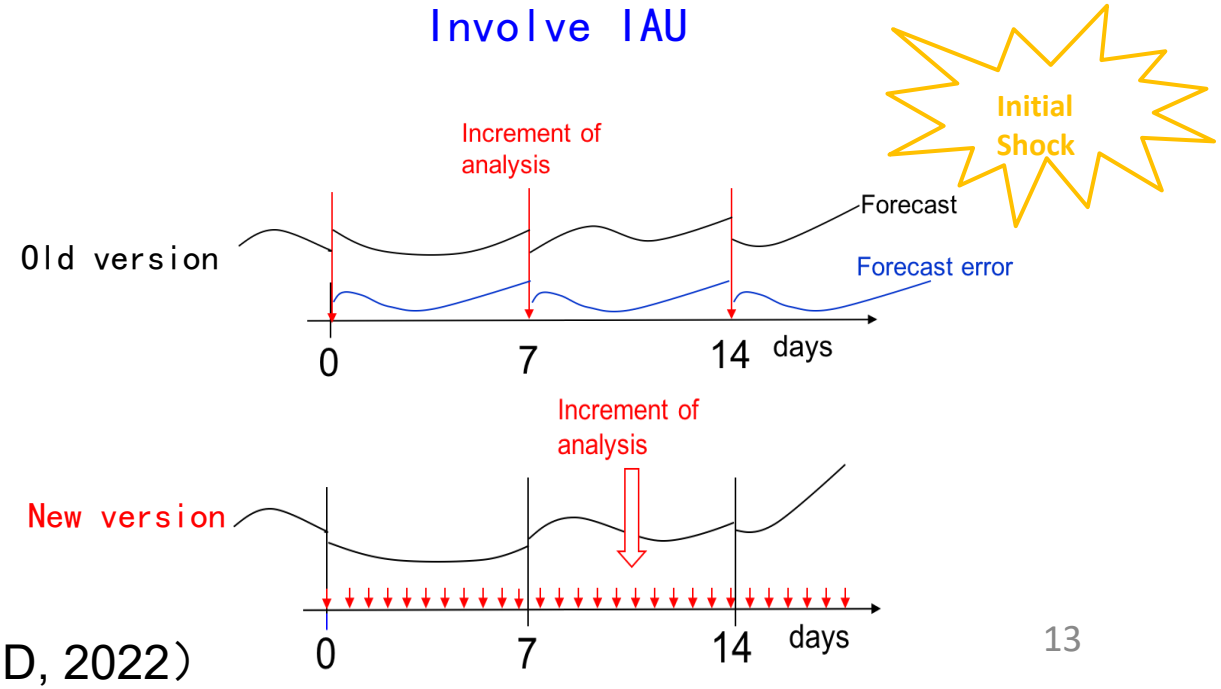
$\tilde{A}$–Hanning filter



Involve FGAT



Involve IAU



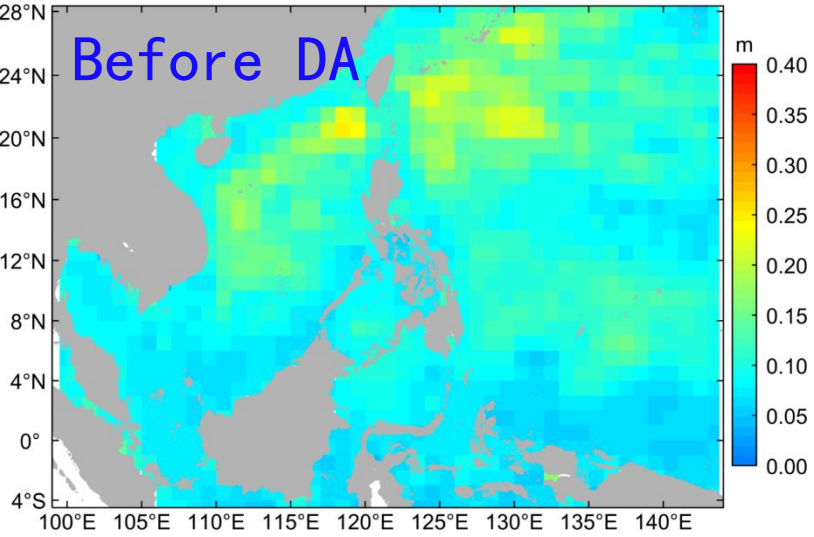
(Zhu et al., GMD, 2022)

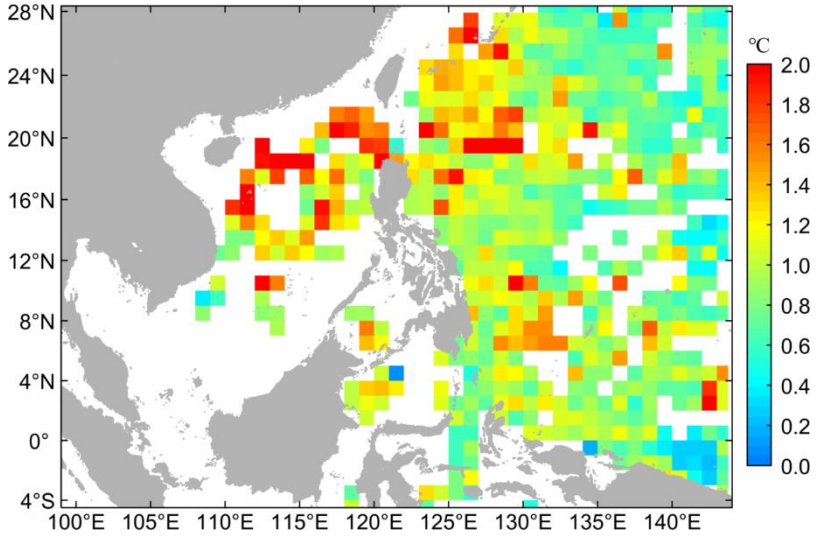
2.6 DA validation

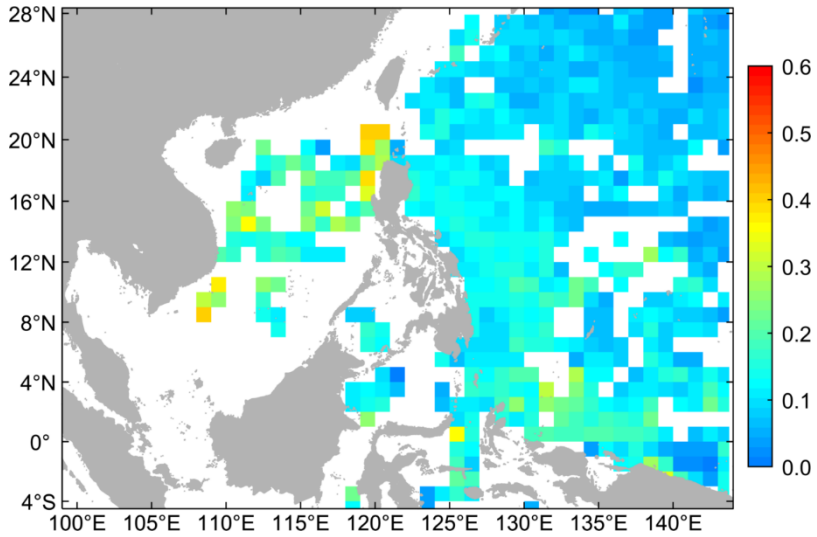
SLA

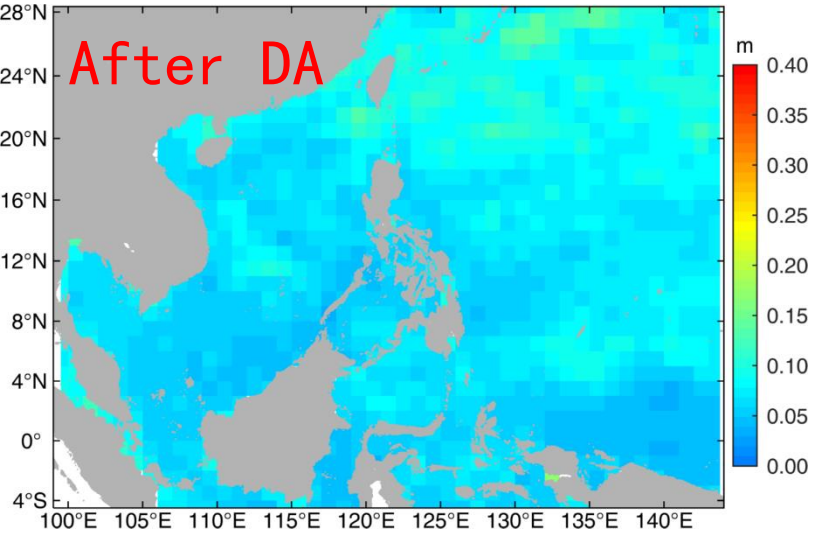
T profile

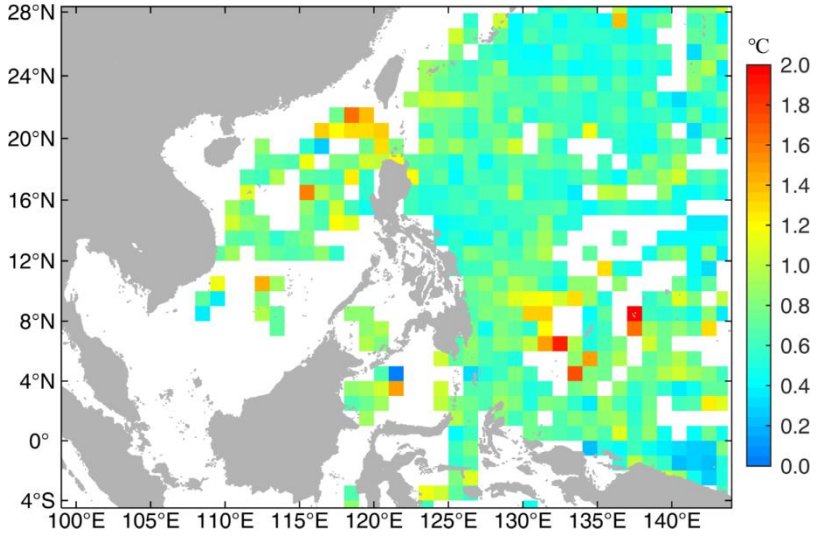
S profile

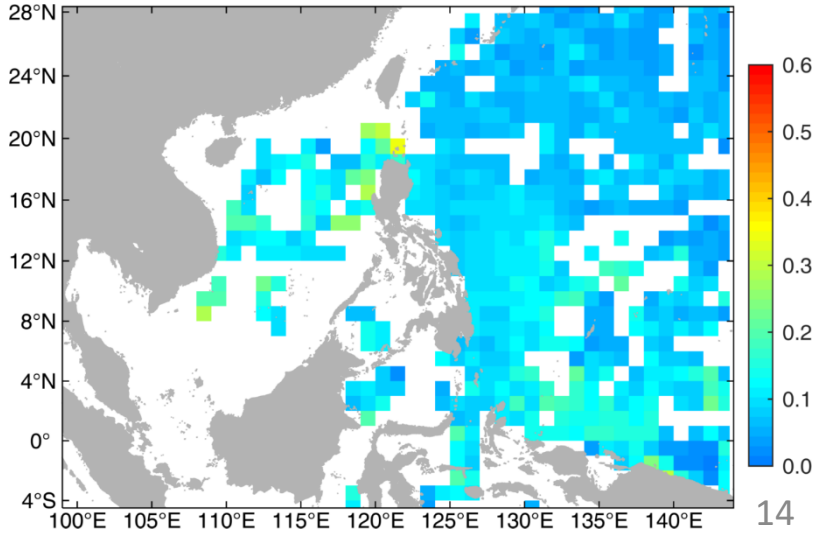






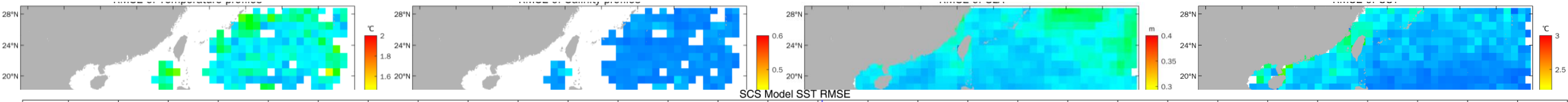


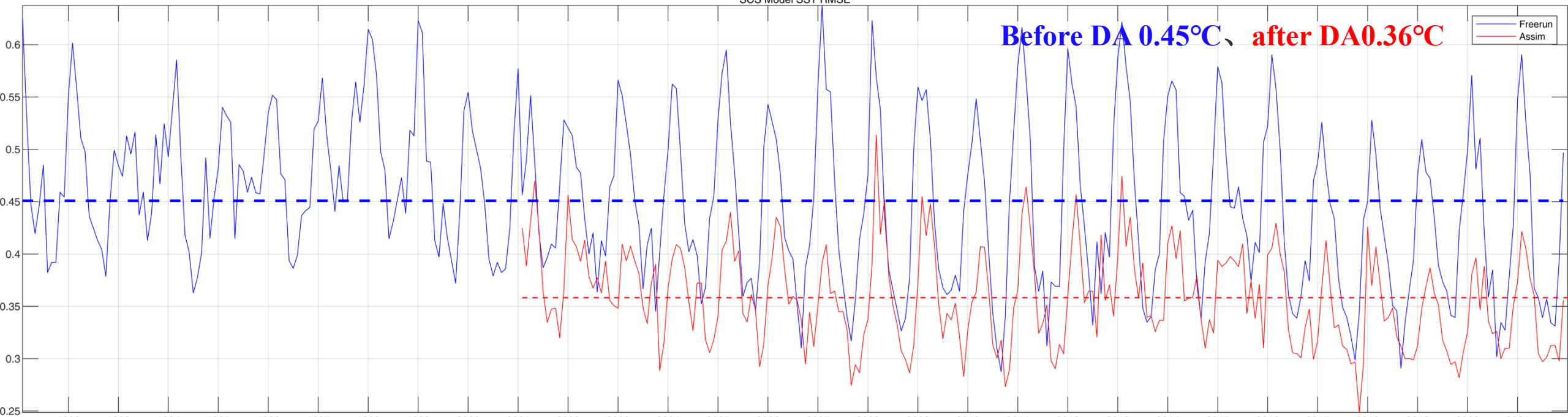


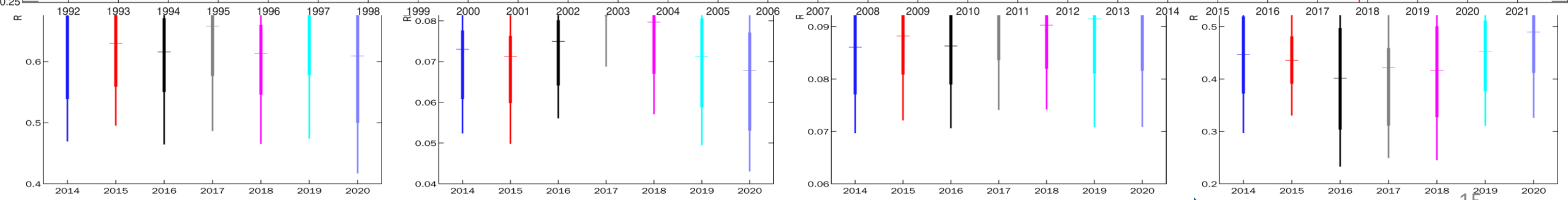


2.6 Analysis system validation

T-profiles **S-profiles** **SLA** **SST**







Different years

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- **GHM-GBA OFS**
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3.1 System settings

Based on ROMSV4.0

Model domain： 19.17-25.1°N，109.7-119°E

Hori. Reso.： 250~1000m

Vert. Reso.： 30 layers

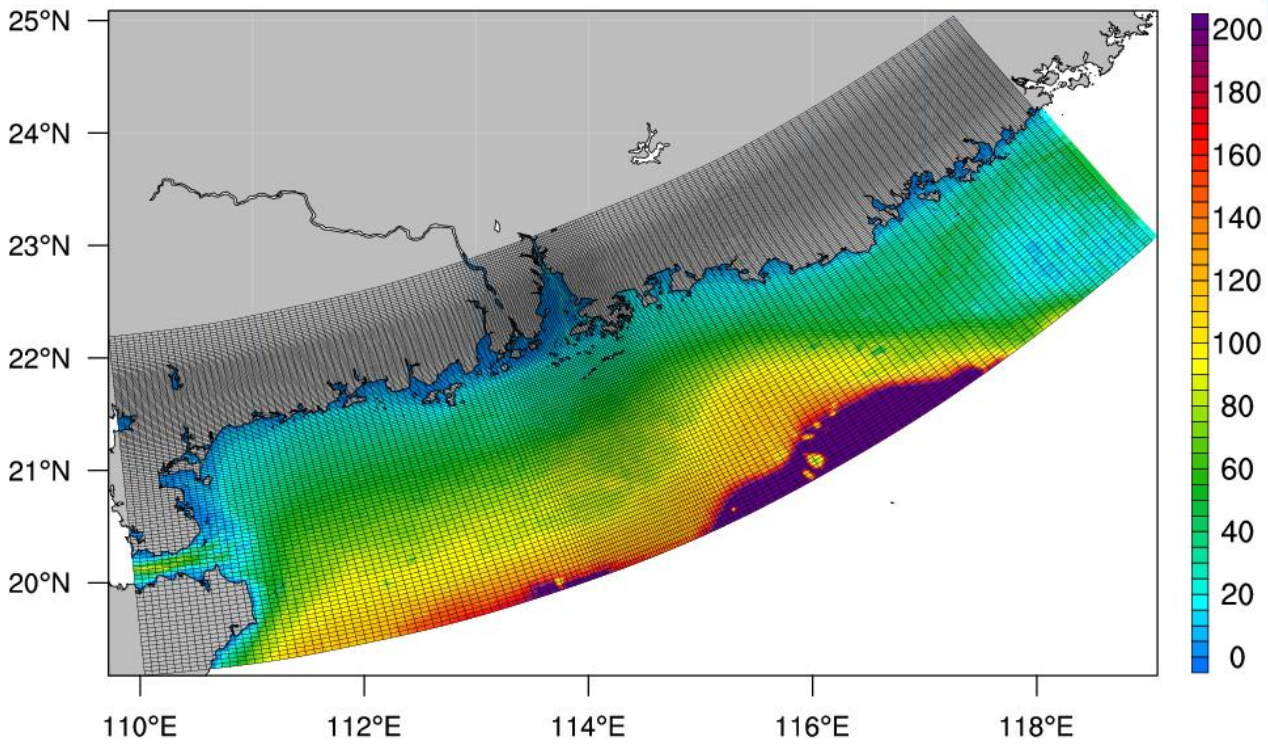
Bathymetry：high reso. Multi-beam measurement

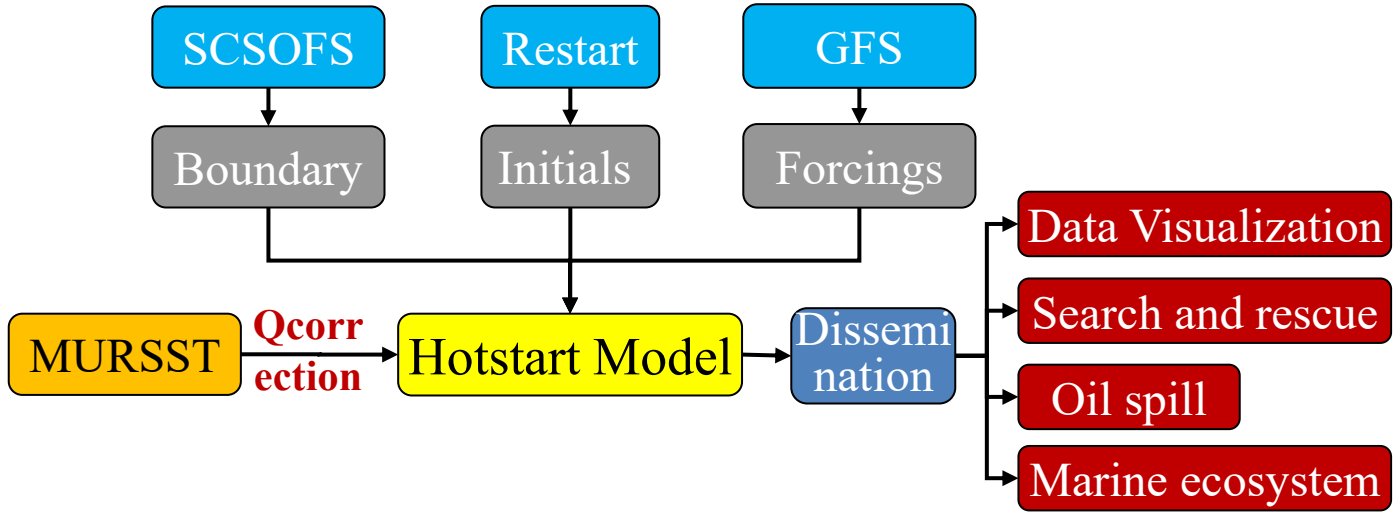
Boundary： SCSOFS

Forcings： GFS at surface

Tides： TPXO9

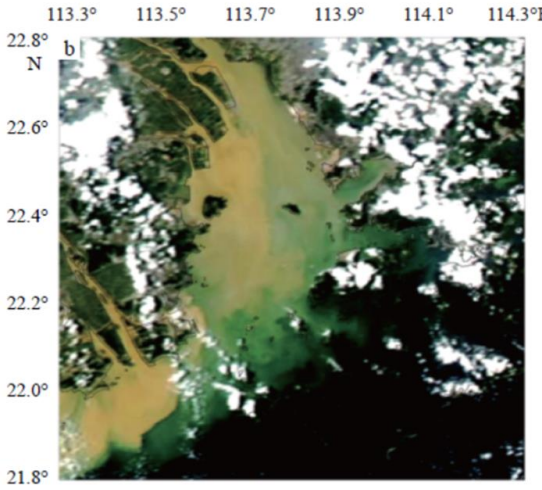
River discharge： **8 river mouths of Pearl River**

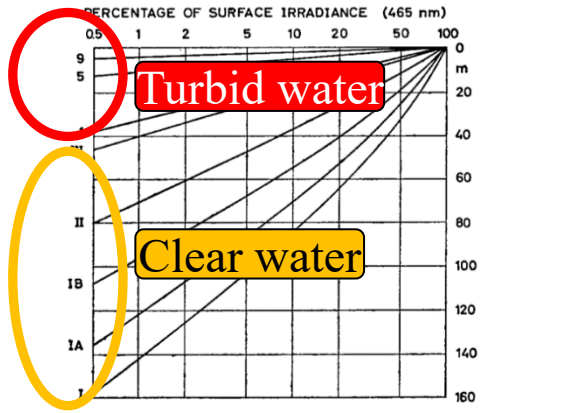




3.2 Optimization of parameterization scheme

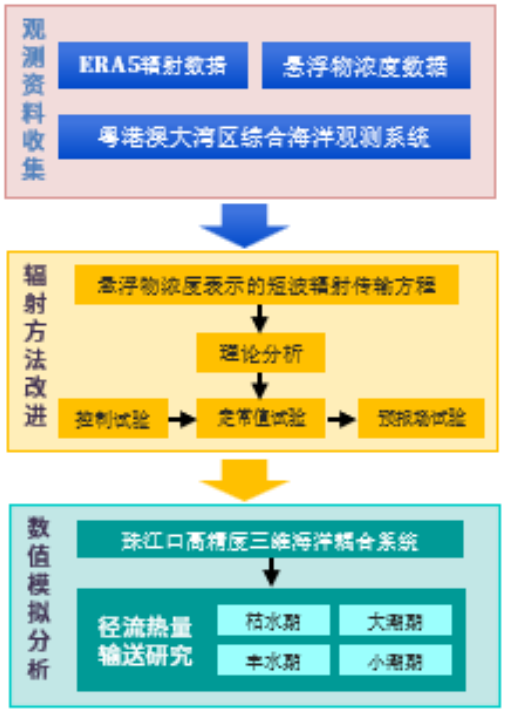
Shortwave Radiation Penetration





ig.49. Depth profiles of downward irradiance in percent of surface radiance for defined optical water types. Oceanic types *I, IA, IB, II, III* and coastal types *1, 5, 9.*

In the nearshore waters of river mouths, rivers carry a large amount of sediment and suspended solids into the ocean. The water near the river mouth is highly turbid, and the impact of shortwave radiation penetration dominating. (Morel &Prieur,1977)



$$I_Z/I_0 = (1-R) \times e^{-Z/L_2} + R \times e^{-Z/L_1}$$

半分析公式(Lee, 2005)

$$I_Z/I_0 = (1-R) \times e^{-K_{IR}(z,\theta_\alpha)Z} + R \times e^{-K_{vis}(IOP,z,\theta_\alpha)Z}$$

$$K_{IR}(z,\theta_\alpha) = [0.560 + 2.304/(0.001+z)^{0.65}](1+0.002\theta_\alpha)$$

$$K_{vis}(IOP,z,\theta_\alpha) = [K_1(IOP) + K_2(IOP)/\sqrt{1+Z}]Z$$

$$K_1(IOP) = [\chi_0 + \chi_1 a^{0.5} + \chi_2 b](1+a_0 sin\theta_\alpha)$$

$$K_2(IOP) = [\zeta_0 + \zeta_1 a + \zeta_2 b](a_1 + a_2 sin\theta_\alpha)$$

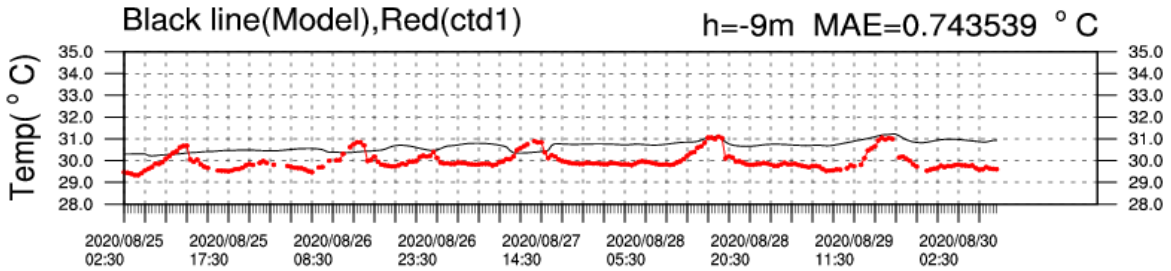
χ_0、χ_1、χ_2、ζ_0、ζ_1、ζ_2、a_0、a_1、a_2均为常系数

珠江口经验关系式

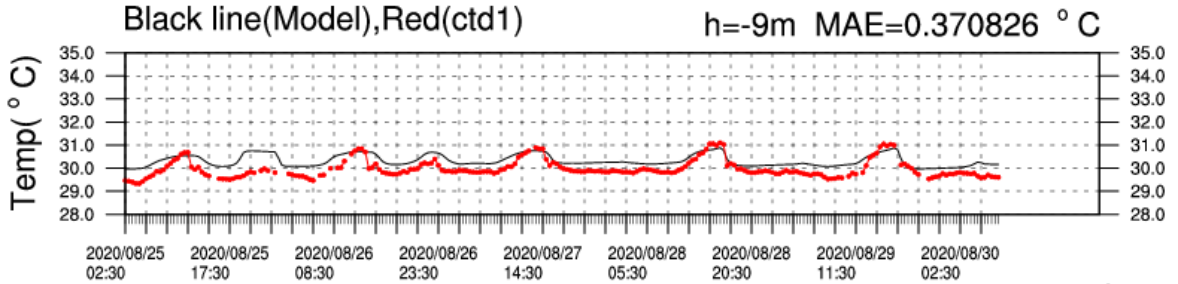
$$a \approx a_w + a_{SPM} = 0.0064 + 0.0423 C_{SPM}$$

$$b \approx b_{SPM} \approx 0.0297 C_{SPM}$$

C_{SPM}为悬沙浓度



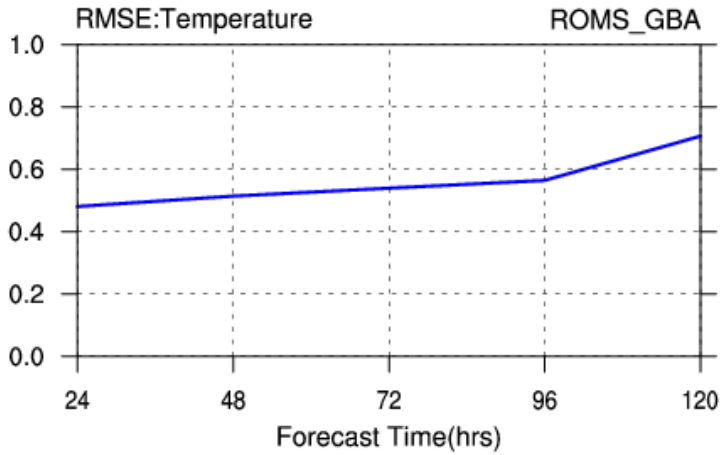
before

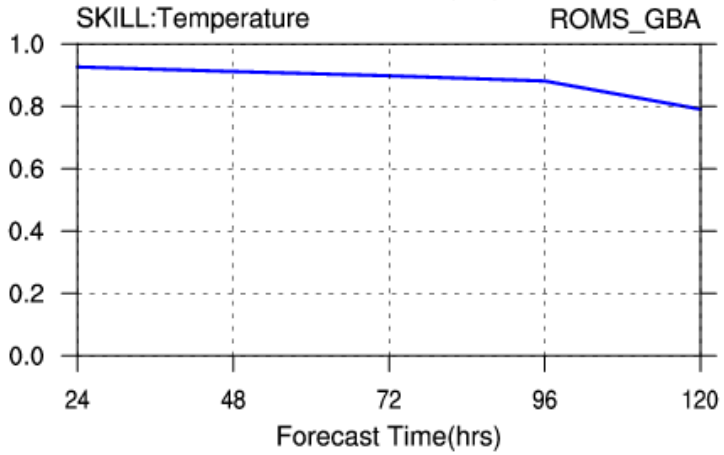


after

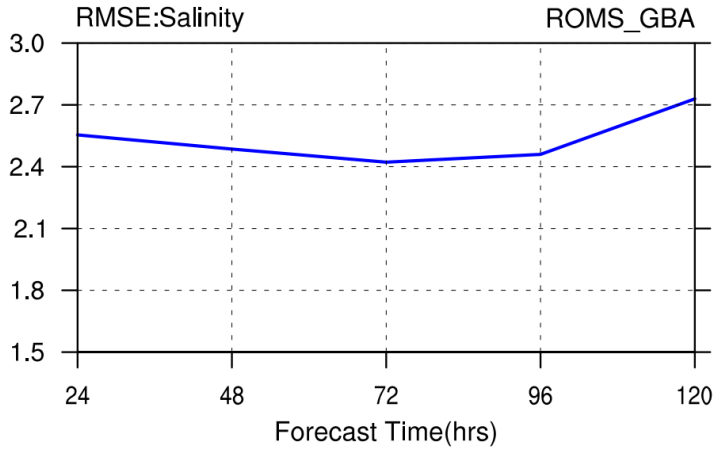
3.3 System forecast validation

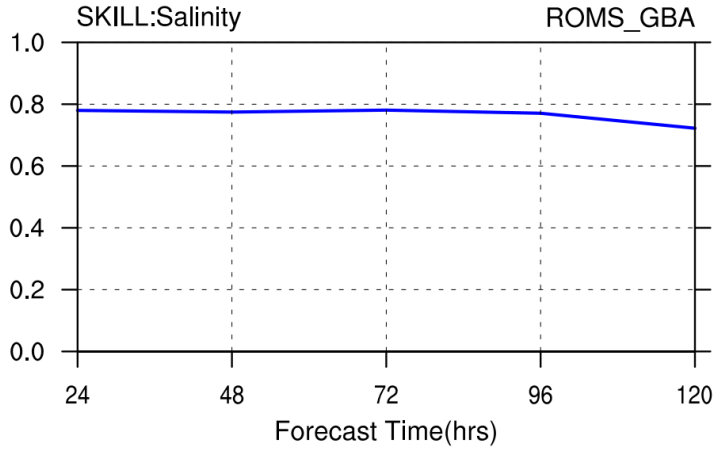
Temp. (°C)



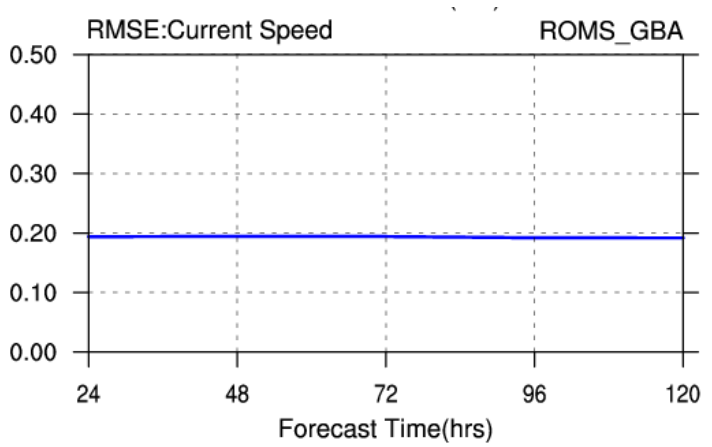


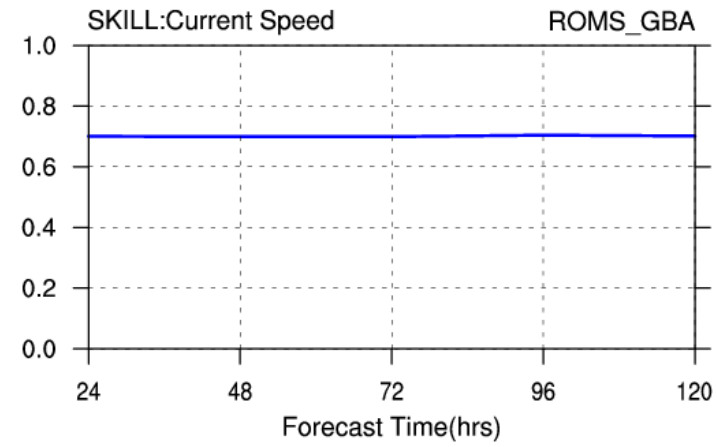
Salt. (PSU)





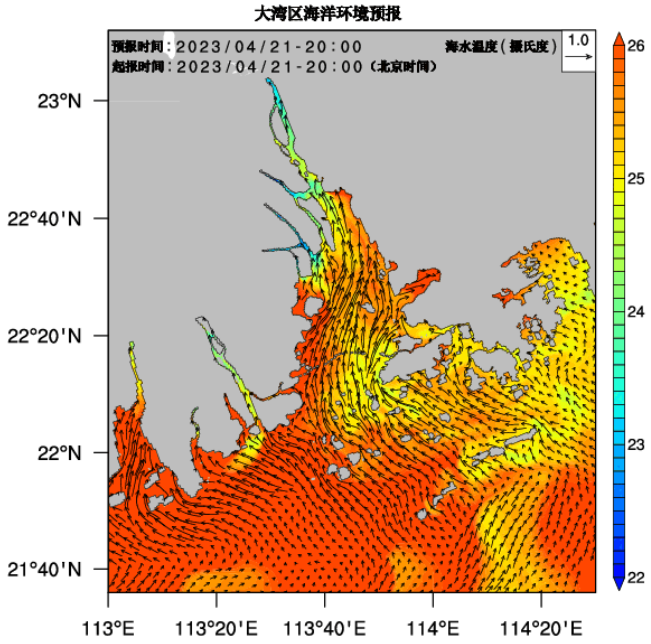
Current (m/s)

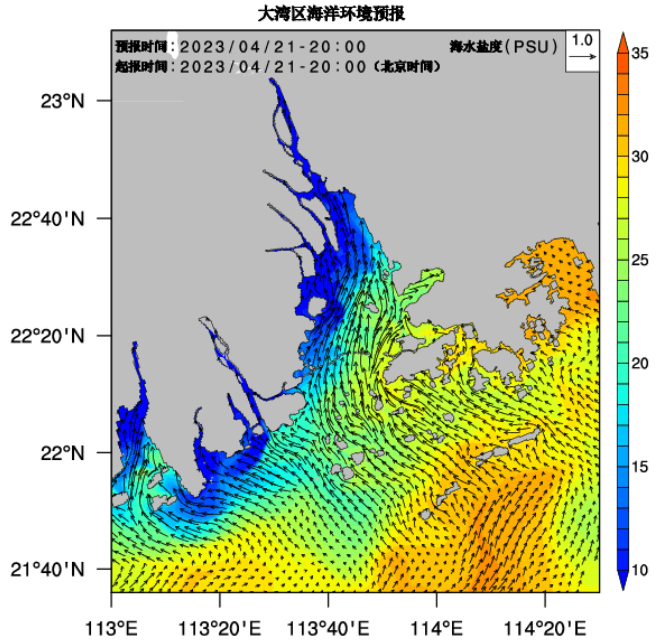


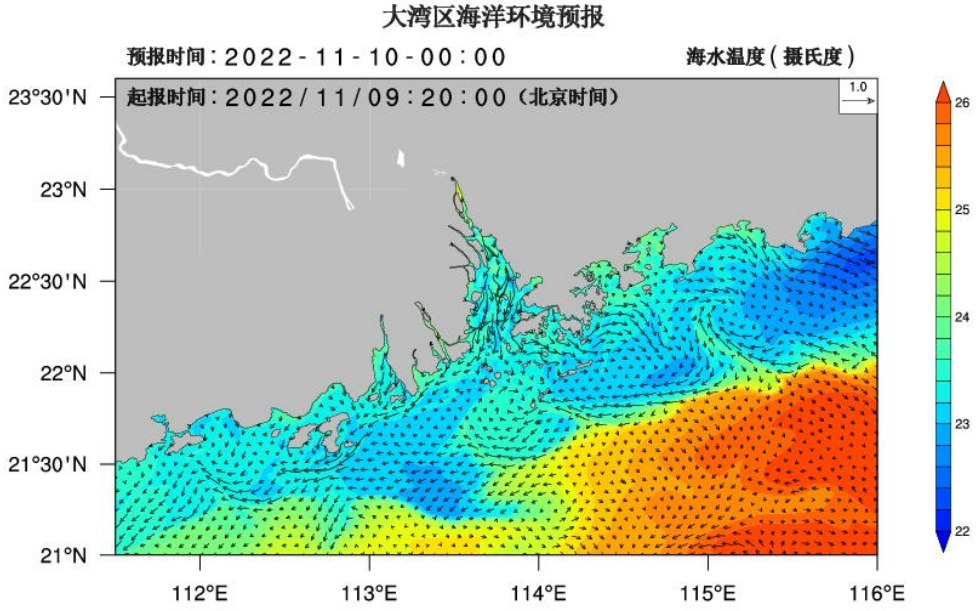


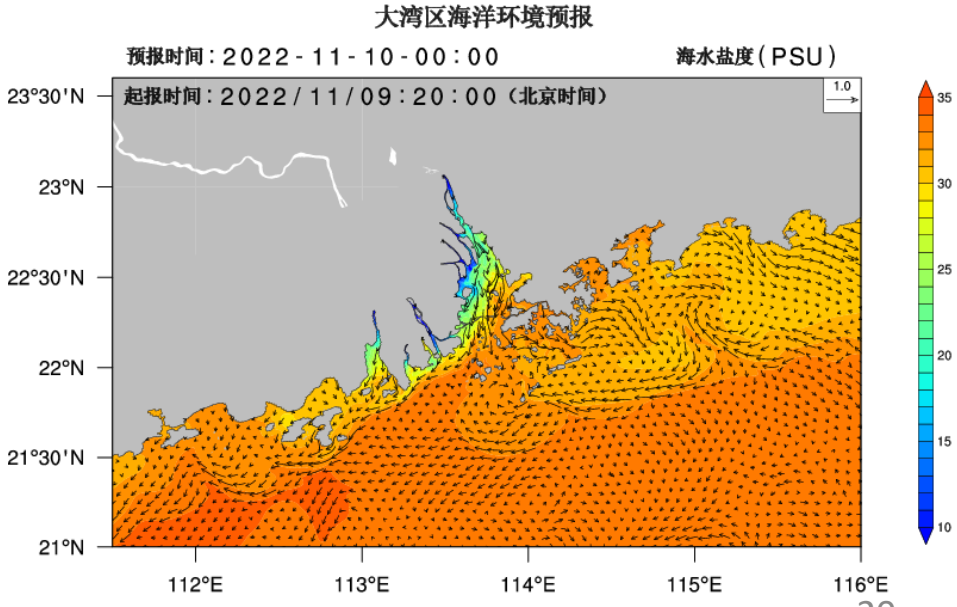
3.4 Forecast products

Forecast	Period	Frequence.	Vert. layers
Water temp.	120 hours	One time each day	30
Water Salt.			
Water Current			
Water level			1





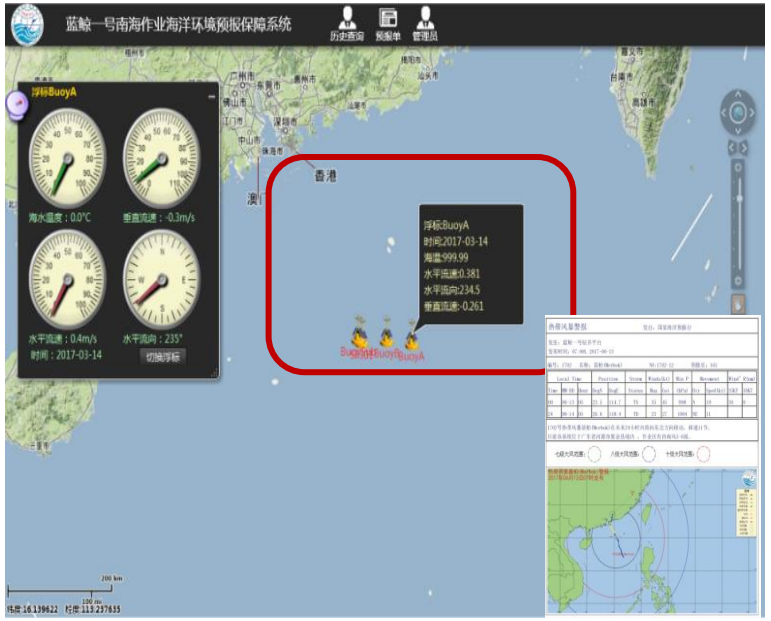


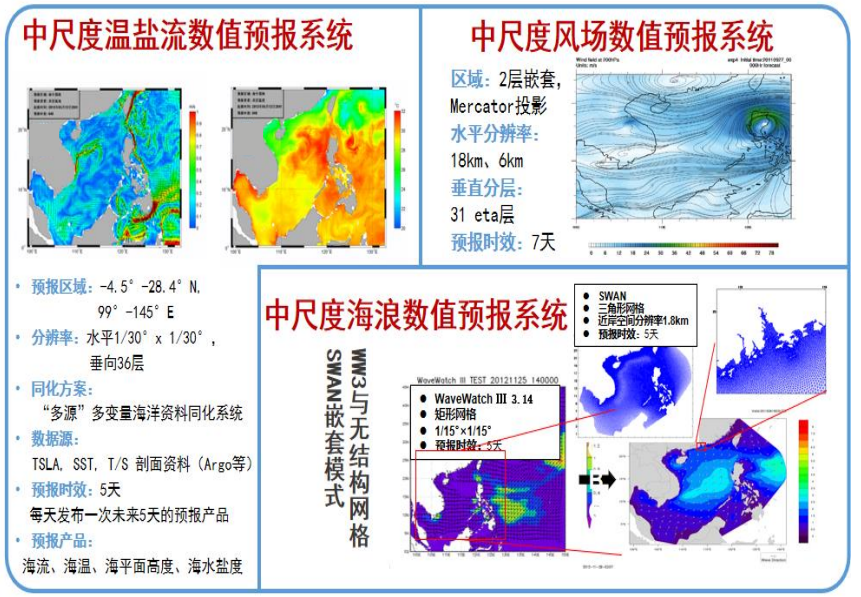


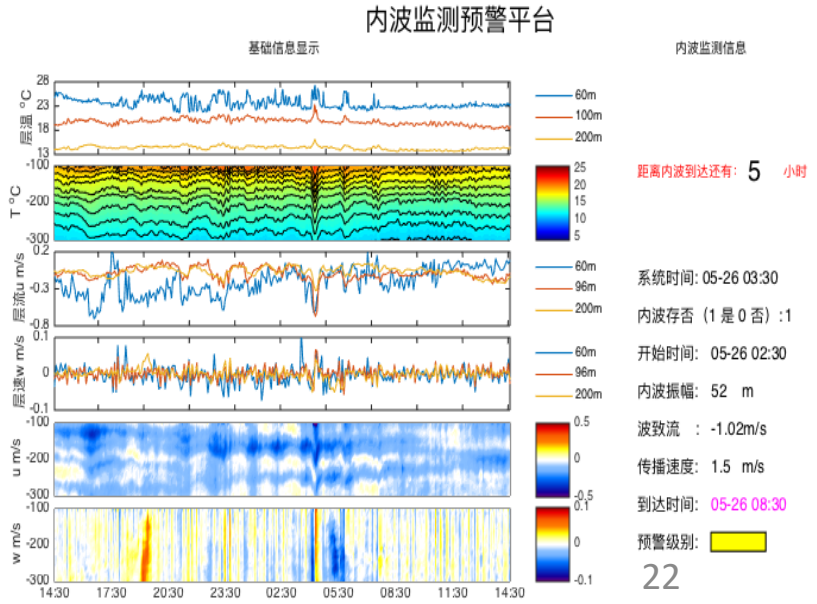
Contents

- Introduction
- SCS OFS
- GHM-GBA OFS
- Applications and future work

4.1 Trial mining of combustible ice







Task requirements：

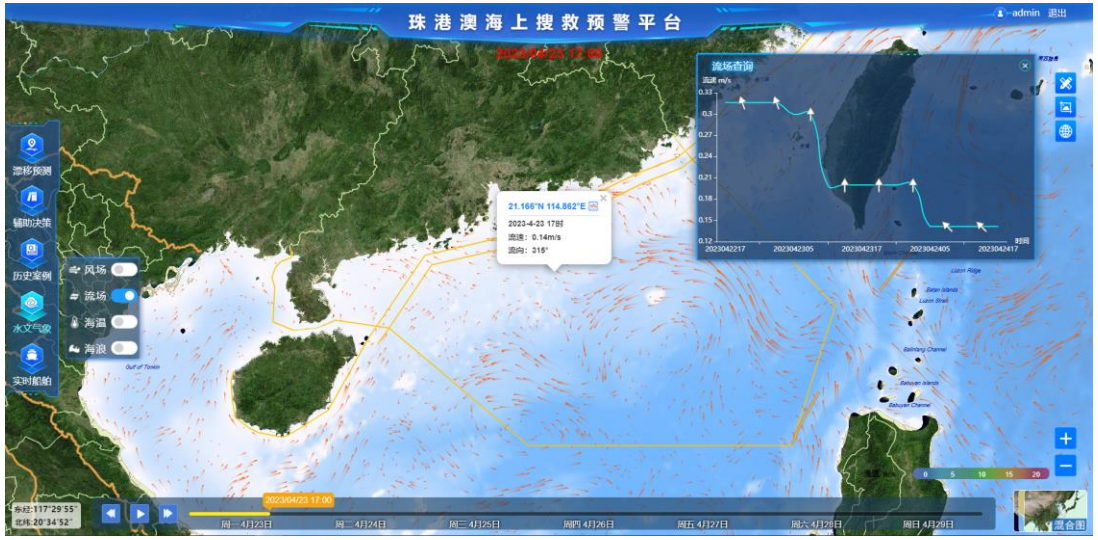
- ‘Blue whale 1’semi submersible platform operational support system
- Marine environment safety guarantee for mining platforms and pipelines

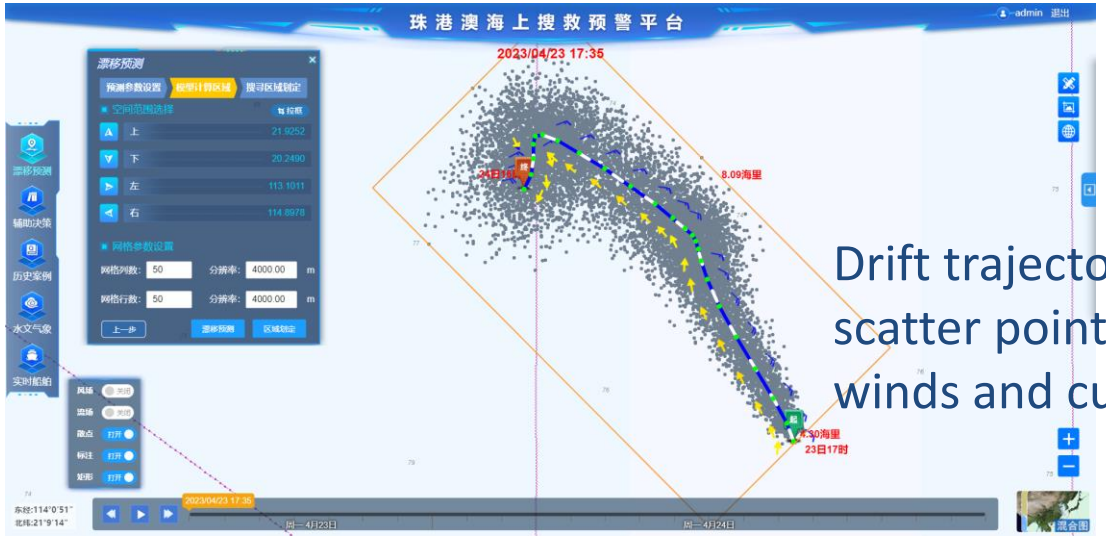
Forecasting area and elements：

- Shenhu area in the NSCS
- Internal wave, winds, wave, currents, temperature and density

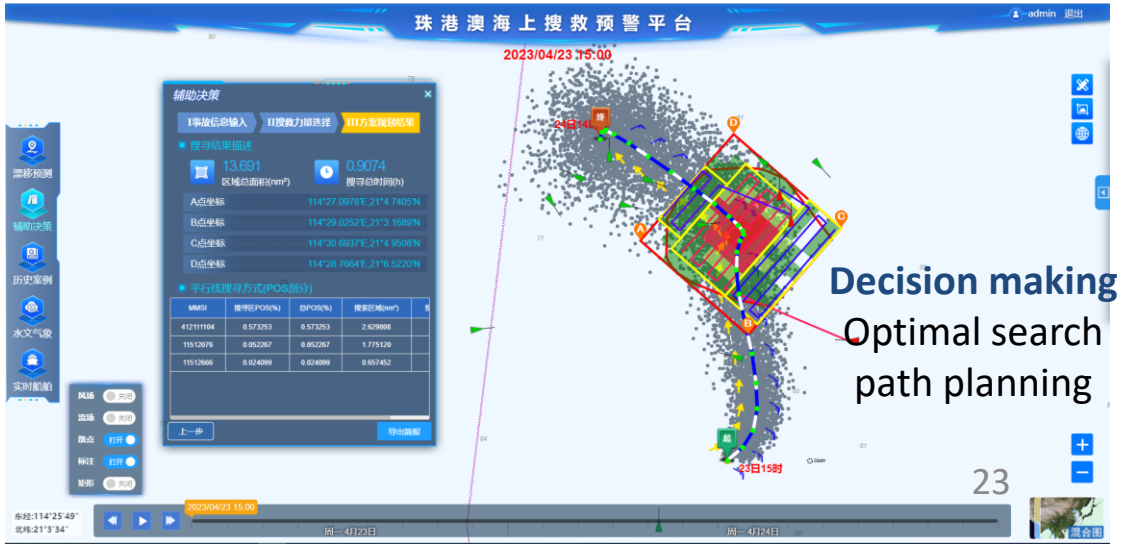
4.2 Zhuhai Hong Kong Macao Maritime Search and Rescue Warning Platform

The platform integrates marine environment forecast data, ship AIS data, search and rescue drift prediction models, and an intelligent decision-making algorithm for maritime search and rescue based on optimal search theory, achieving accurate prediction of the drift trajectory of maritime targets and intelligent assisted decision-making for search and rescue.





Drift trajectory, scatter points, winds and currents

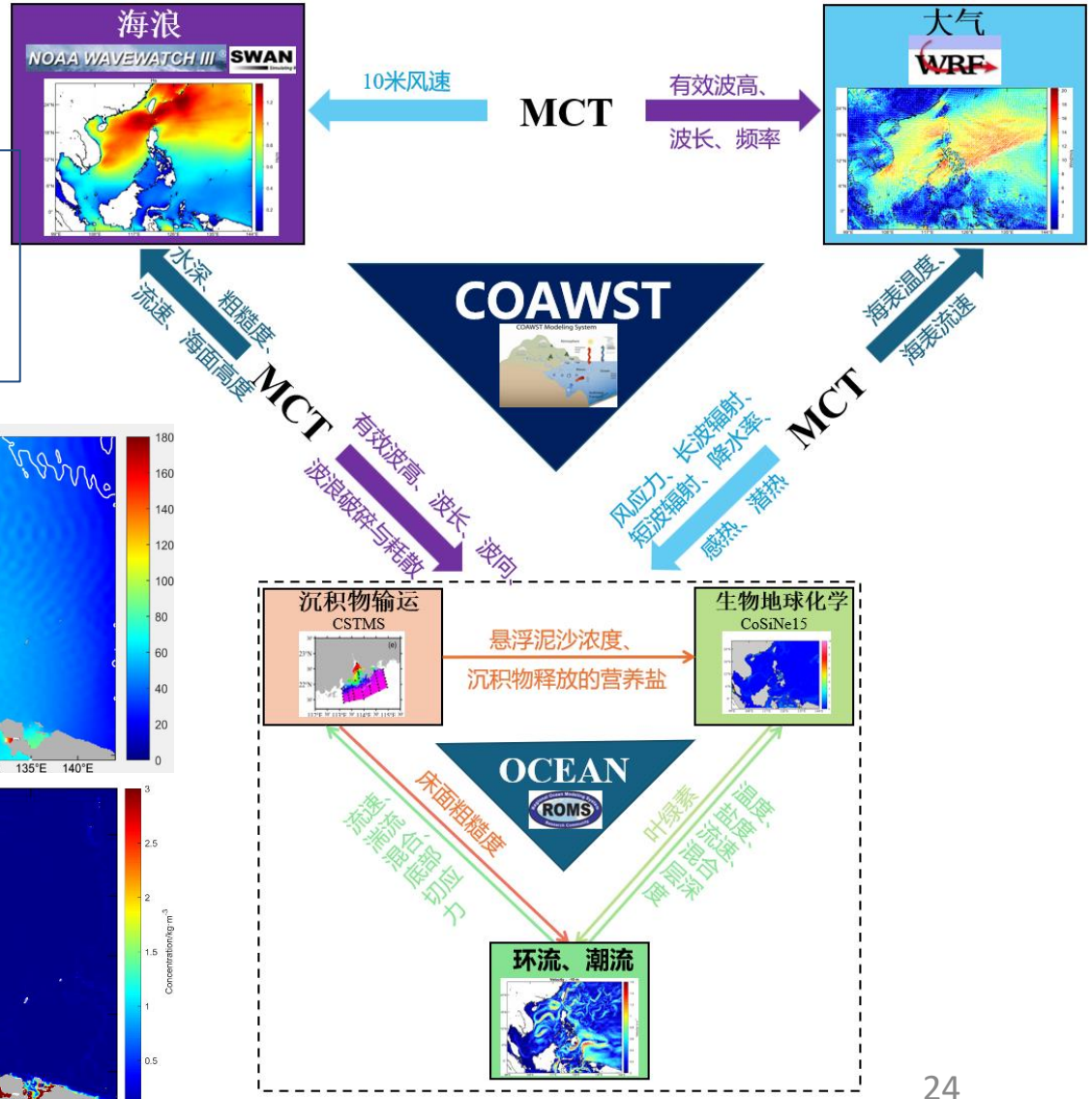


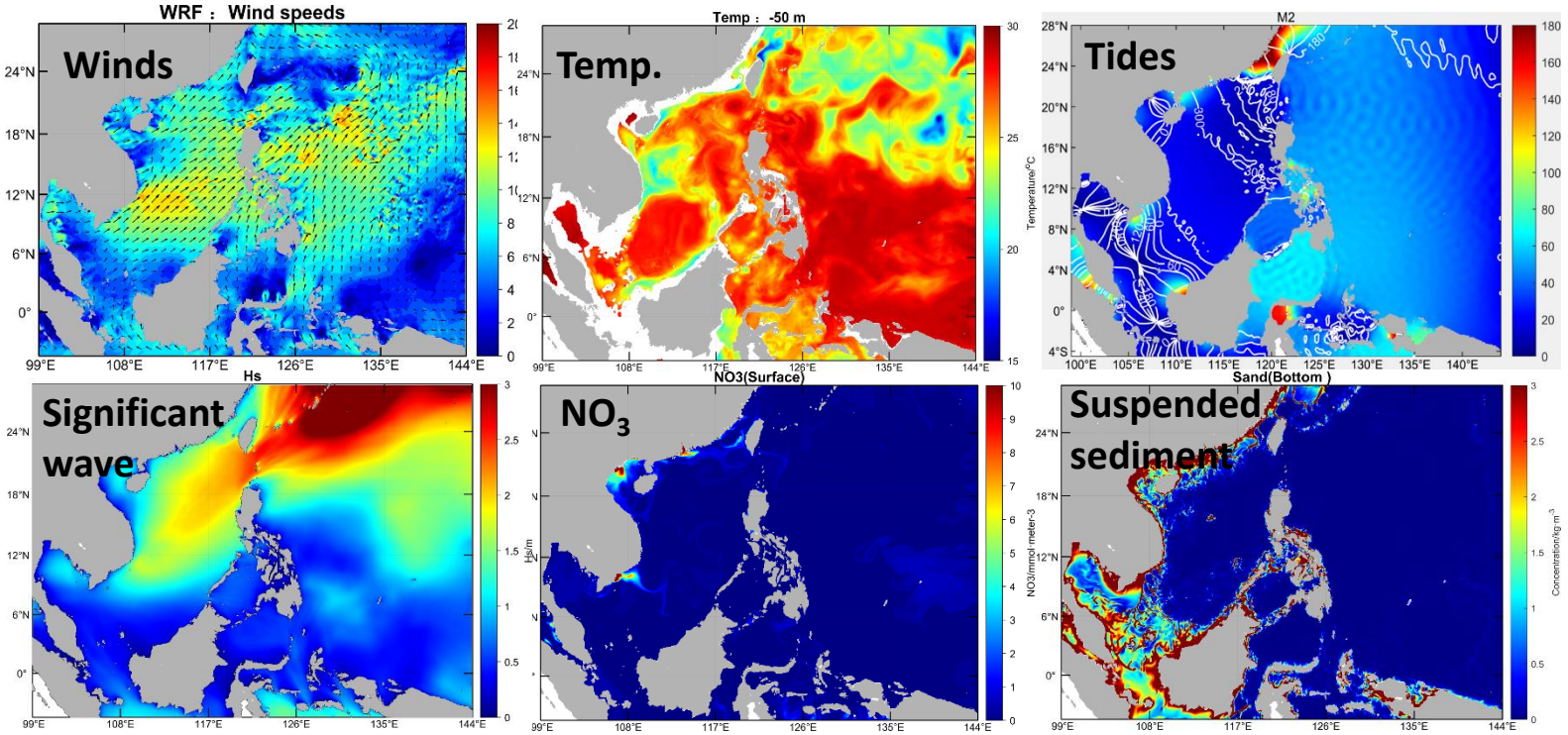
Decision making
Optimal search path planning

4.3 Cross sphere fully coupled numerical model in the SCS

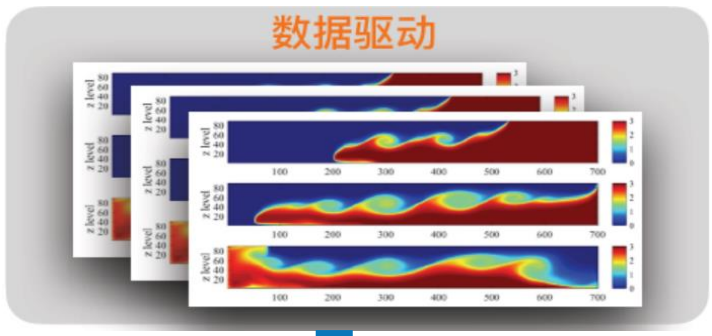
Cross sphere atmosphere-current-tide-wave-ecology-sediment fully coupled model in the SCS is constructed based on the COAWST framework.

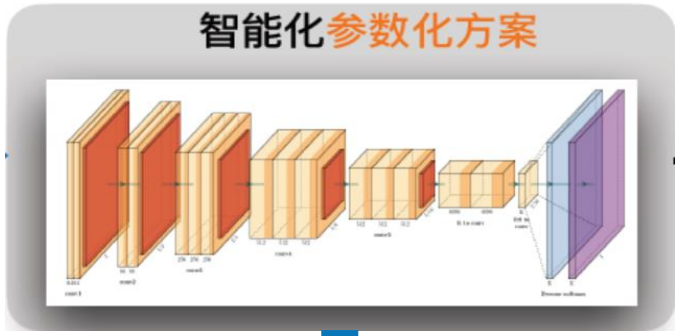
- ✓ Atmo.- WRF model 30km、10km two layer nesting
- ✓ Ocean-ROMS+CoSiNE model 9km~4km
- ✓ Wave-WW3 model 16km、9km~4km two layers nesting



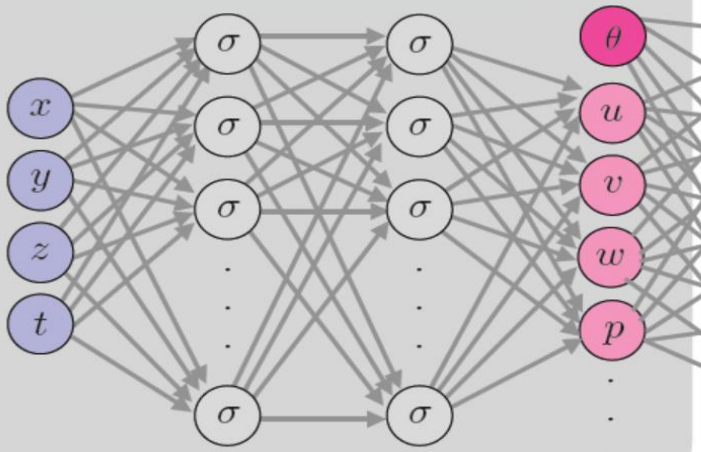


4.4 Data-knowledge coupled intelligent marine forecast model

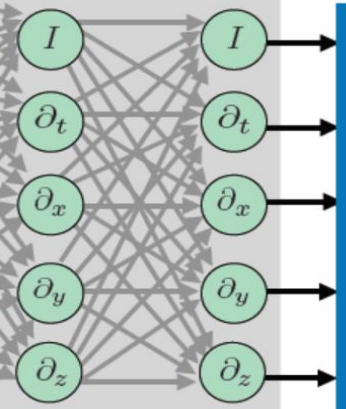




深度神经网络构建



自动求导



原始方程组（物理驱动）

$f_1 = \frac{\partial F}{\partial t} + \mathcal{L}(F) - \mathcal{G}(F)$

初值条件

$f_2 = F - \mathcal{G}_{IV}(F)$

边值条件

$f_3 = \frac{\partial F}{\partial n} - \mathcal{G}_{BV}(F)$

数据同化目标函数

$f_4 = \frac{1}{2}(\mathbf{x} - \mathbf{x}^b)^T B^{-1}(\mathbf{x} - \mathbf{x}^b) + \frac{1}{2}(H(\mathbf{x}) - \mathbf{y})^T R^{-1}(H(\mathbf{x}) - \mathbf{y})$

· · · · · ·

- 时变项 $\frac{\partial u}{\partial t}$
- 压强梯度力 $\frac{1}{\rho}\frac{\partial p}{\partial x}$
- 科氏力 fv
- 平流项 $u\frac{\partial u}{\partial x}$
- 摩擦项 $\frac{\partial}{\partial x}\left(A_H \frac{\partial u}{\partial x}\right)$
- ……

损失函数设计

最小化

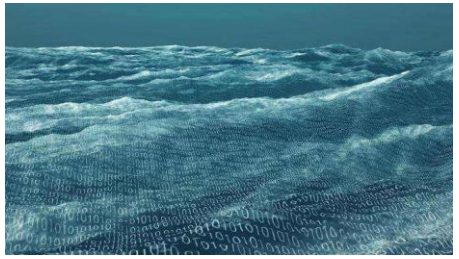
$$L = \Sigma_i(\lambda_i f_i) = \lambda_1 f_1 + \lambda_2 f_2 + \lambda_3 f_3 + \lambda_4 f_4$$

4.5 Digital twins of the ocean: concept and framework

Digital twins are realistic digital representations of physical assets. **Digital Twin of the Ocean** is a consistent, high-resolution, multi-dimensional, real-time virtual representation of the ocean, combining ocean observations, artificial intelligence, advanced modelling operating on high-performance computers and accessible to all.

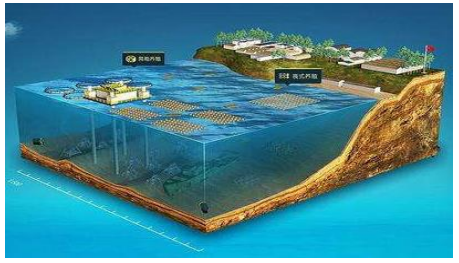
Tasks of a DTO for the GBA

1. Construct a data lake for full lifecycle governance of relevant data



2. Develop data-knowledge coupled marine forecasting techniques

3. Realize online computation and multi-dimensional visualization

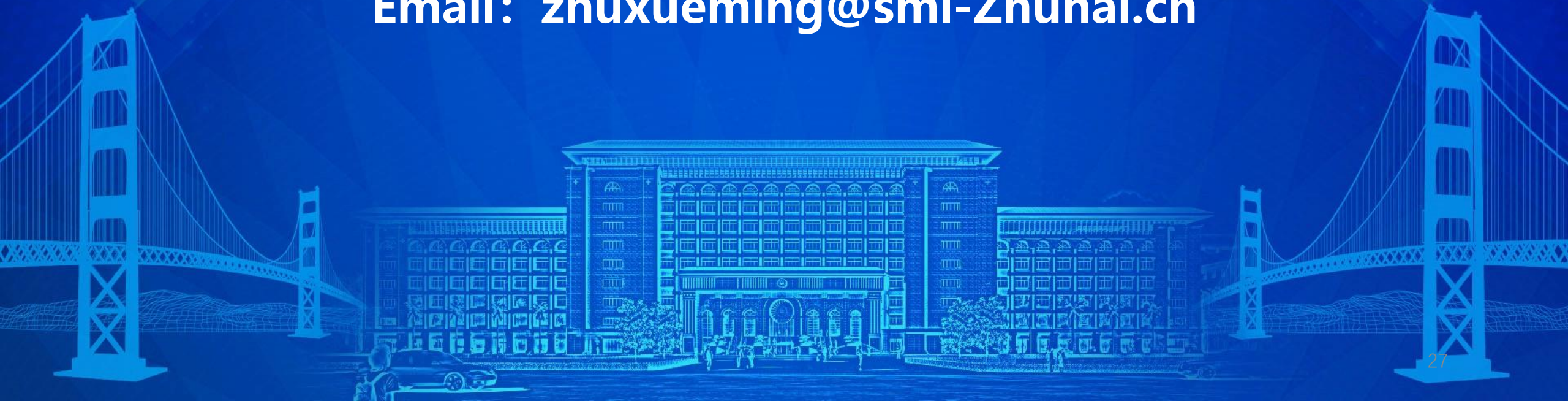


4. Set up decision-making services for ecosystem-based management

南方海洋科学与工程广东省实验室（珠海）
Southern Marine Science and Engineering Guangdong Laboratory(Zhuhai)

Thanks for your listening

Email：zhuxueming@sml-Zhuhai.cn



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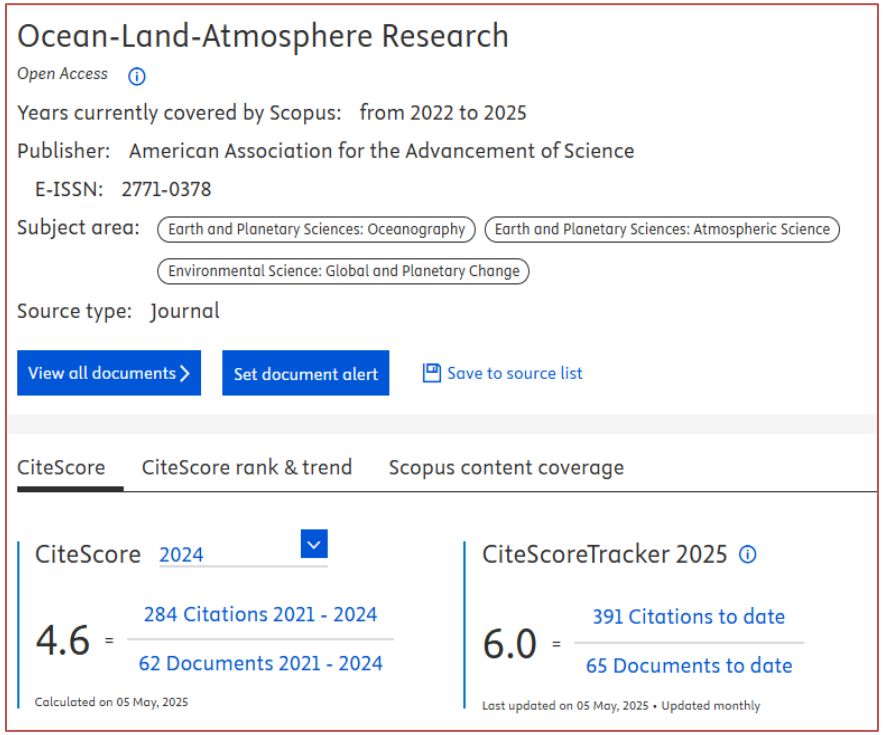

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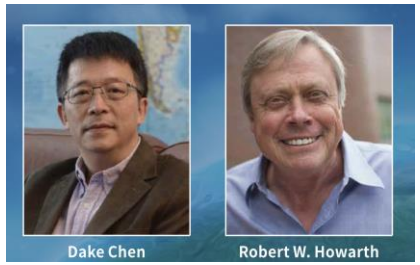

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