Numerical study and prediction of green macroalgae blooms and particle trajectories in the Yellow sea

Guimei LIU, Shan GAO, Liang ZHAO, Xuanliang JI
Natinal Marine Environmental Forecasting Center, Beijing, China

Victoria, BC, Canada
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Outline

1. Historical analysis

2. Numerical study and verification in 2016/2017

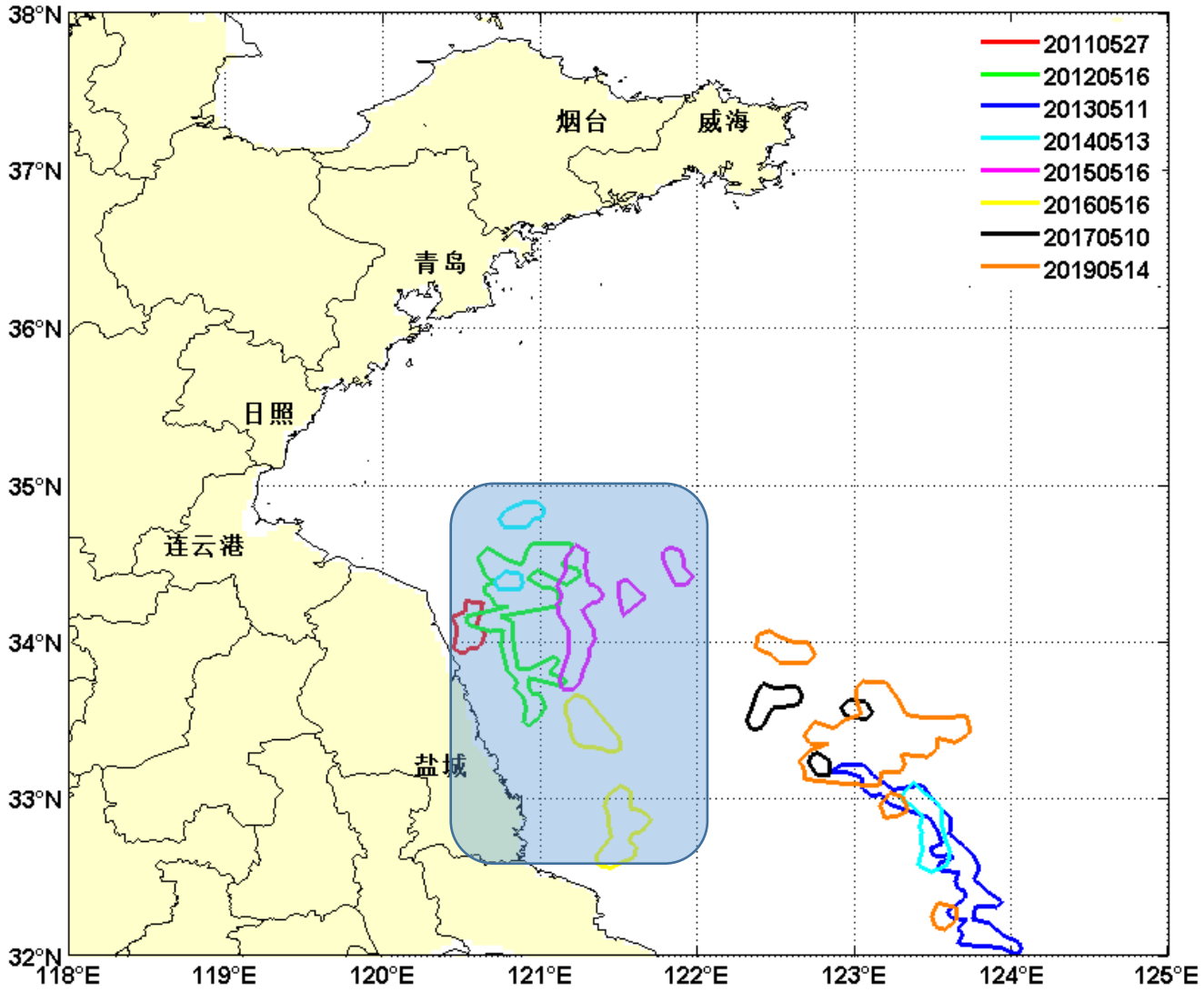
3. Prediction and analysis of green macroalgae in 2019

4. Operational ecological forecasting systems in China

Characteristics of green macroalgae outbreak for the first time in historical years

Remote sensing historical data from National Satellite Ocean Application Service：

- ✓ Outbreak regions： offshore of the east coastal region of Yancheng, Jiangsu
- ✓ Outbreak time: from the middle of May to June
- ✓ Outbreak form: fragmentary, stripe, etc.

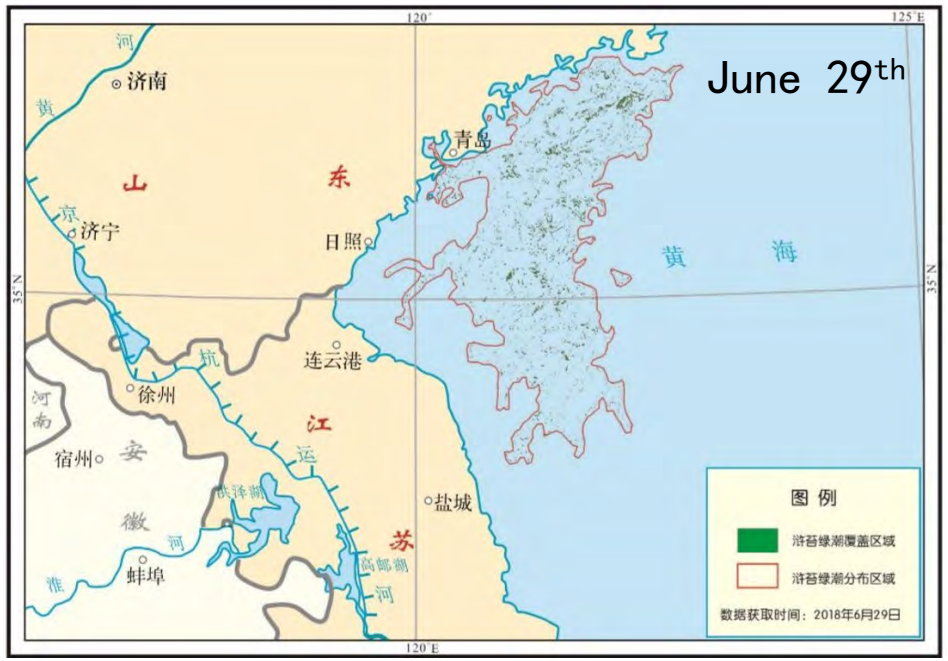


Annual variation characteristics of green macroalgae in the Yellow Sea

《China Marine disaster bulletin》

- In recently five years, the green macroalgae was the most serious in 2015, with the maximum coverage area reaching about 600km^2. 535,400 tons of Enteromorpha accumulated near the Qingdao coastal regions, that is five times of the amount 2014.
- The green macroalgae of 2018 is the weakest in nearly five years, characterized by longer duration, smaller distribution area and coverage area. The maximum coverage area has been the lowest since the observation records from 2008.

Year	Outbreak Time	Death Time	Maximum distribution area（km^2）	Maximum coverage area（km^2）
2014	Early April	Middle August	50000	540
2015	Middle April	Early August	52700	594
2016	Early May	Early August	57500	554
2017	Middle May	Middle July	29522	281
2018	Late May	Middle August	38046	193



Development of green macroalgae in the Yellow sea

Late April, southwest of Yellow Sea, near Jiangsu coastal areas

Middle May, gathering into pieces, could be found by satellites

Late May-Early June, gathering in the western Yellow sea, Haizhou Bay

Middle June-Middle July, influencing south of Shandong, and gathering near coastal areas

Late July-August，gradually withering away

- It generally takes 3 months from its eruption to extinction, and takes about 5 months.

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Green macroalgae eco-dynamic model in the Yellow Sea

——particle trajectories, growth and extinction

Temperature
- Range: 10-30℃
- Optimal: 15-25℃

Light
- Range: 1000-10000lx
- Optimal: 5000-6000lx

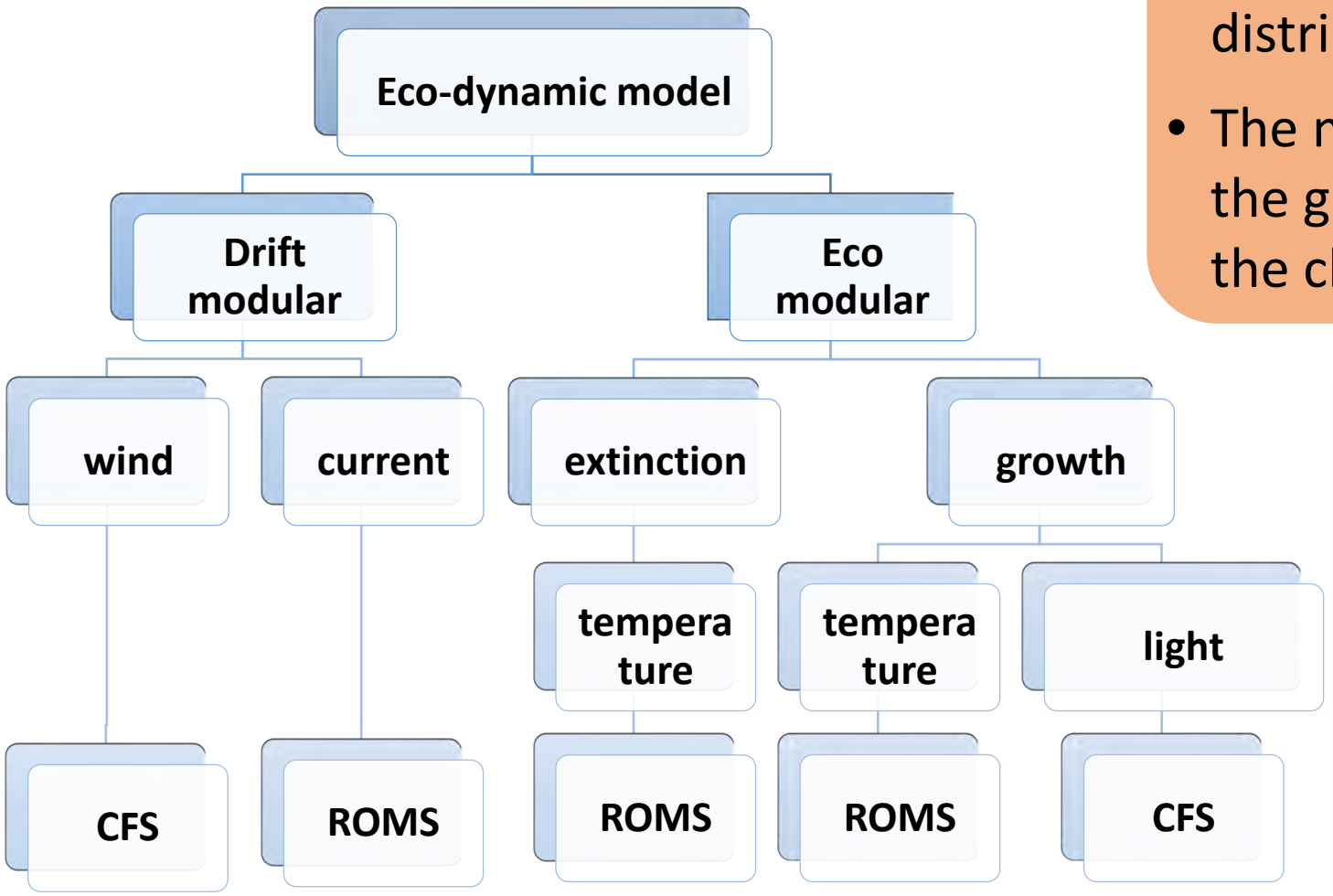
Salinity
- Range: 7.2-35
- Optimal: 20.2-26.9

pH
- Range: 6-9
- Optimal: 7-9

According to the ecological experiment and in-situ observation, Temperature and light are the most important factor for the development of green algae.

- Green tide has strong environmental adaptability
- The daily growth rate can reach 10%-37% under suitable conditions.

Green macroalgae eco-dynamic model in the Yellow Sea



- The model can simulate the distribution of green tide.
- The model can predict the drift path of the green tide, the affected area and the change of relative biomass.

Drift modular

Particle trajectories

$$\frac{dx}{dt} = v_{ax}(x,y,,t) + R \times v_d(x,y,t)\cos(\theta - \beta)$$

$$\frac{dy}{dt} = v_{ay}(x,y,,t) + R \times v_d(x,y,t)\sin(\theta - \beta)$$

x, y position

$v_a(x,y,t)$ current

$v_d(x,y,t)$ wind θ direction angle

R drag coefficient β Drag angle

The effect of wind on green tide particles

：

- dirfting velocity
- dirfting direction

Eco modular

Growth and extinction (temperature)

Following Epply(1972)'s equation the growth rate of green algae is set as:

$$G_T = G_{\max}\theta^{T-T_{\max}}$$

$G_{\max}$ Growth rate at $T_{\max}(20^{\circ}C)$

θ Temperature-dependent coefficient

Growth (light)

The light limitation function follows Steele(1962)

$$L_{limit} = \frac{I}{I_o}e^{(1-\frac{I}{I_o})}$$

I_o is optimal light intensity.

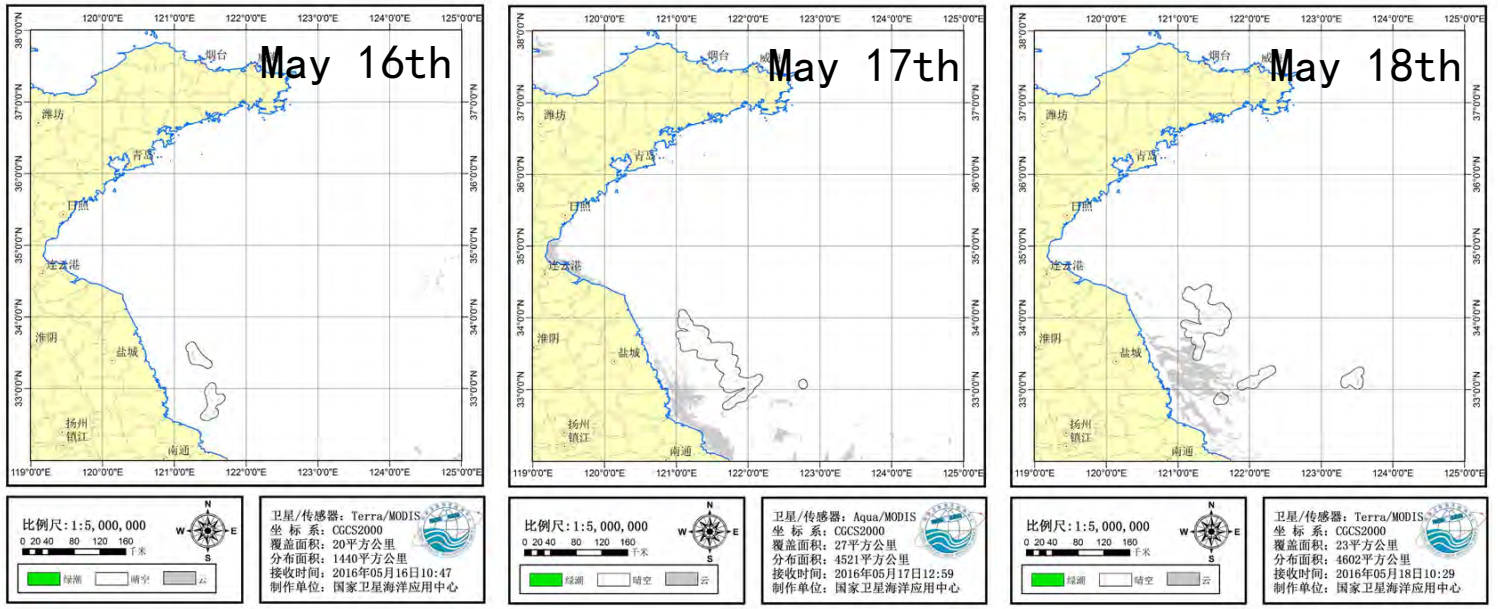
Total growth rate

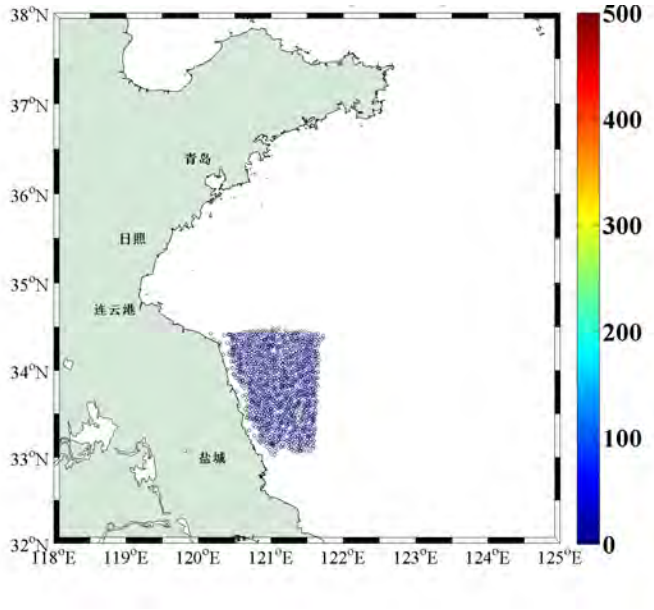
$$G = G_T * L_{limit}$$

Numerical study and verification in 2016

On May 16th 2016, near the eastern Yancheng coastal areas, the outbreak of green tide was monitored by MODIS during successive days, covering with an area of about 20 square kilometers.

MODIS remote sensing data

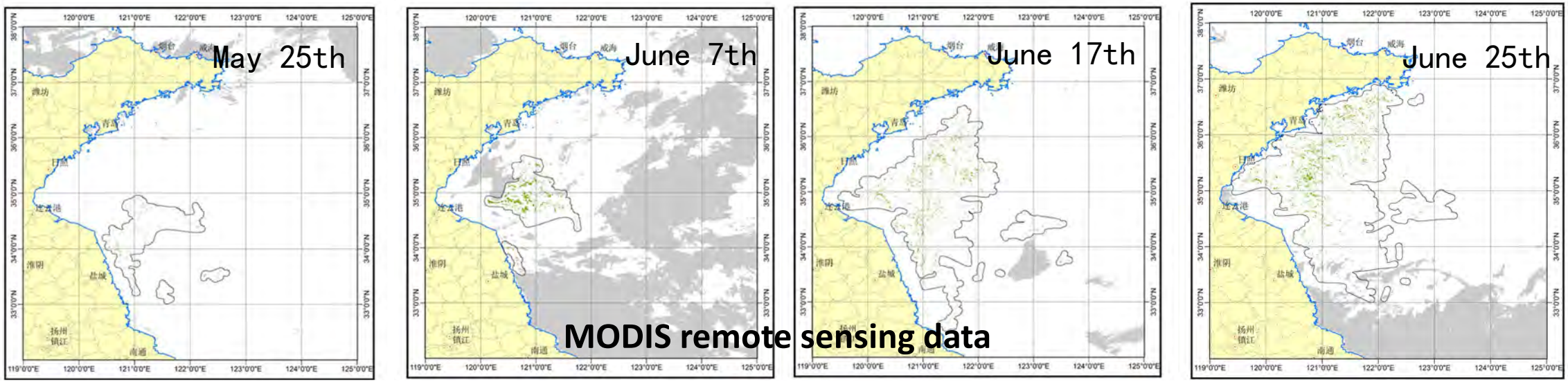


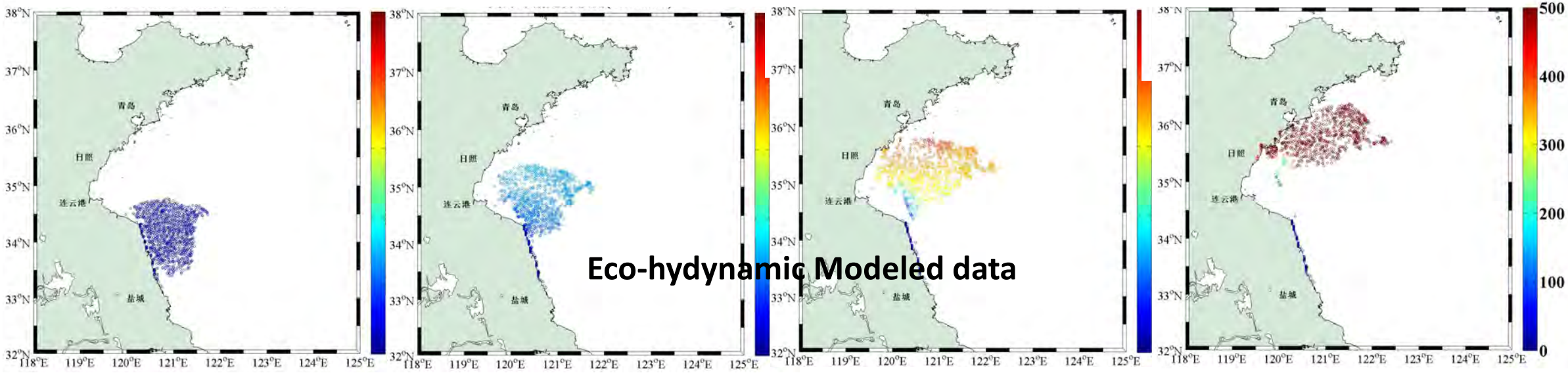


CFSR forcing：~0.25°，current、wind、light、temperature；Model：ROMS，resolution~3km；

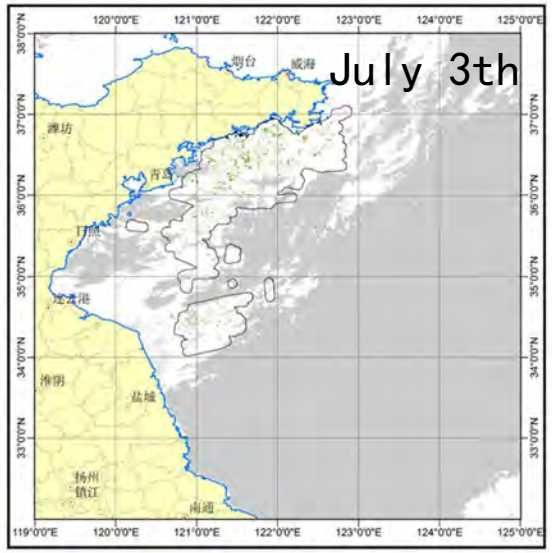
Duration：5.15-8.31；Initial position： the eastern Yancheng (119.8-121.5; 33-34.5)；

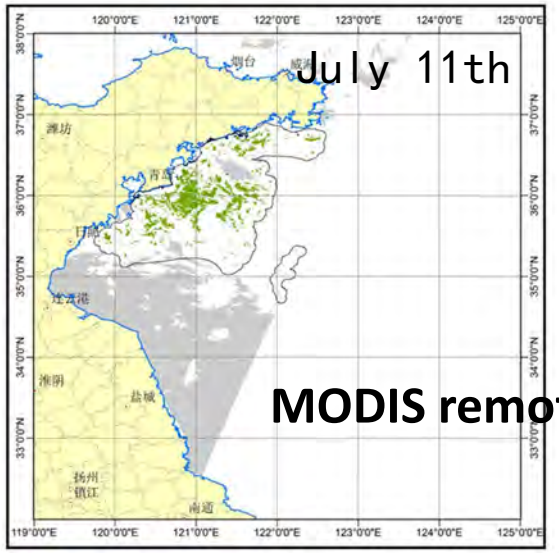
particles：1248

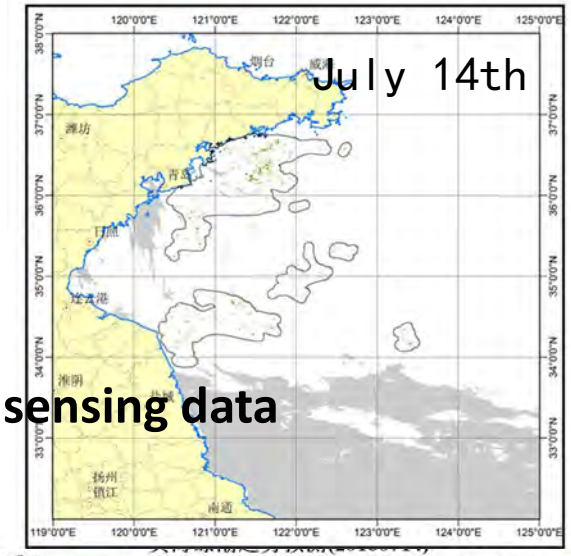




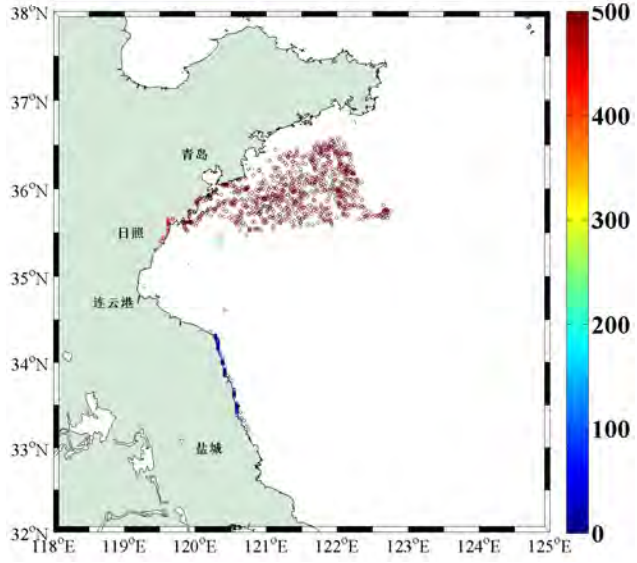
On June 12th, there appeared green macroalgae in parts of the sea of Lianyungang coast. On June 19th, it gathered near Rizhao coast; On June 20th, it drifted near Qingdao coast; and then on June 22nd near Rushan, Weihai; in late June, marcroalgae successively influenced Lianyungang, Rizhao, Qingdao, Yantai etc.

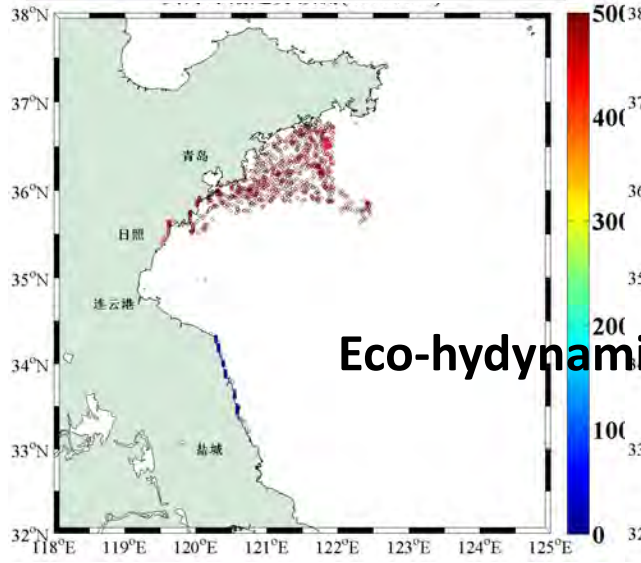


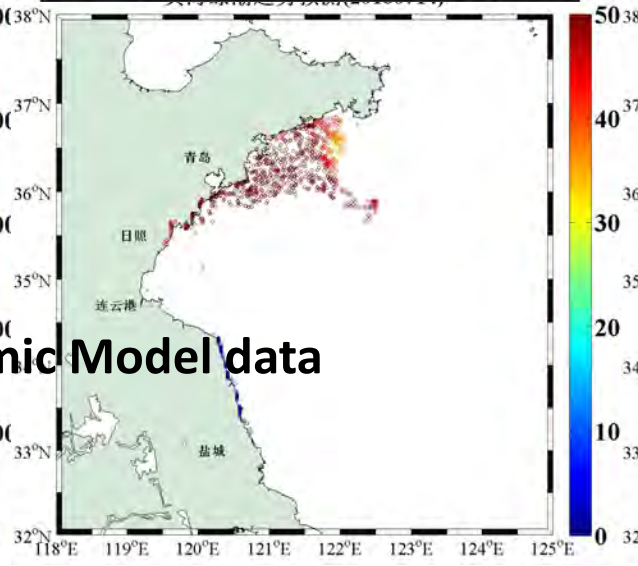


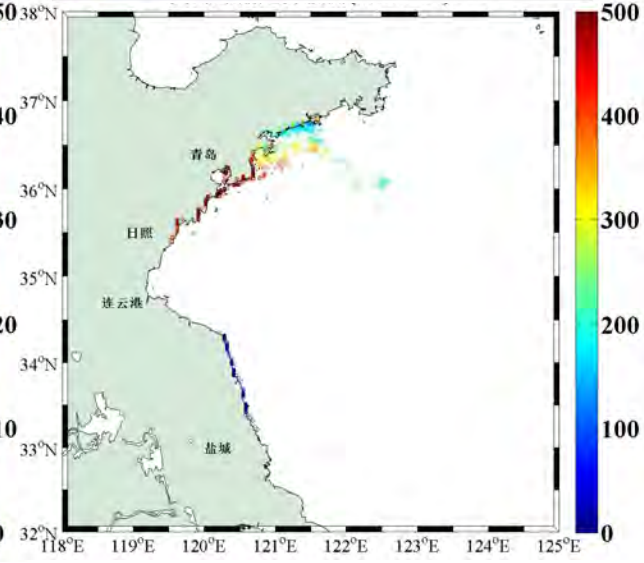


MODIS remote sensing data







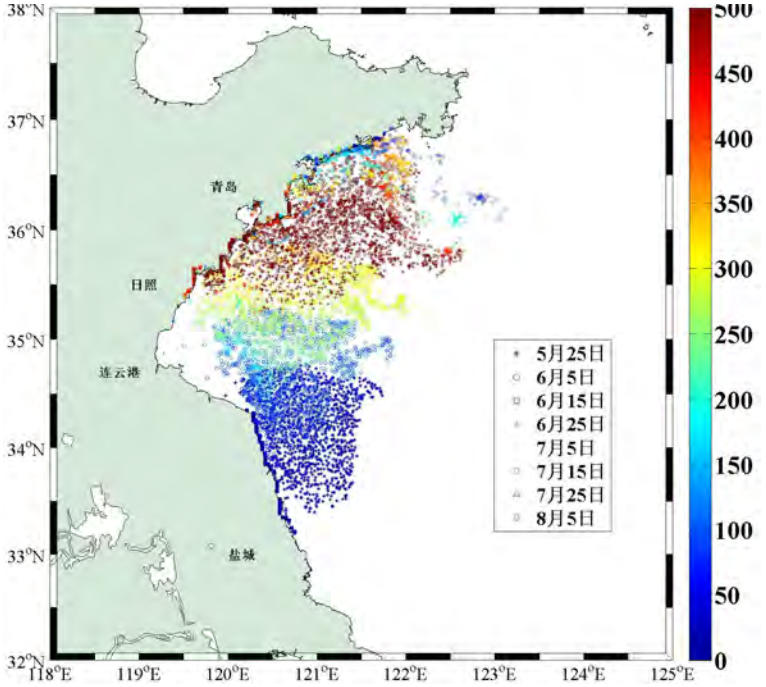


Eco-hydynamic Model data

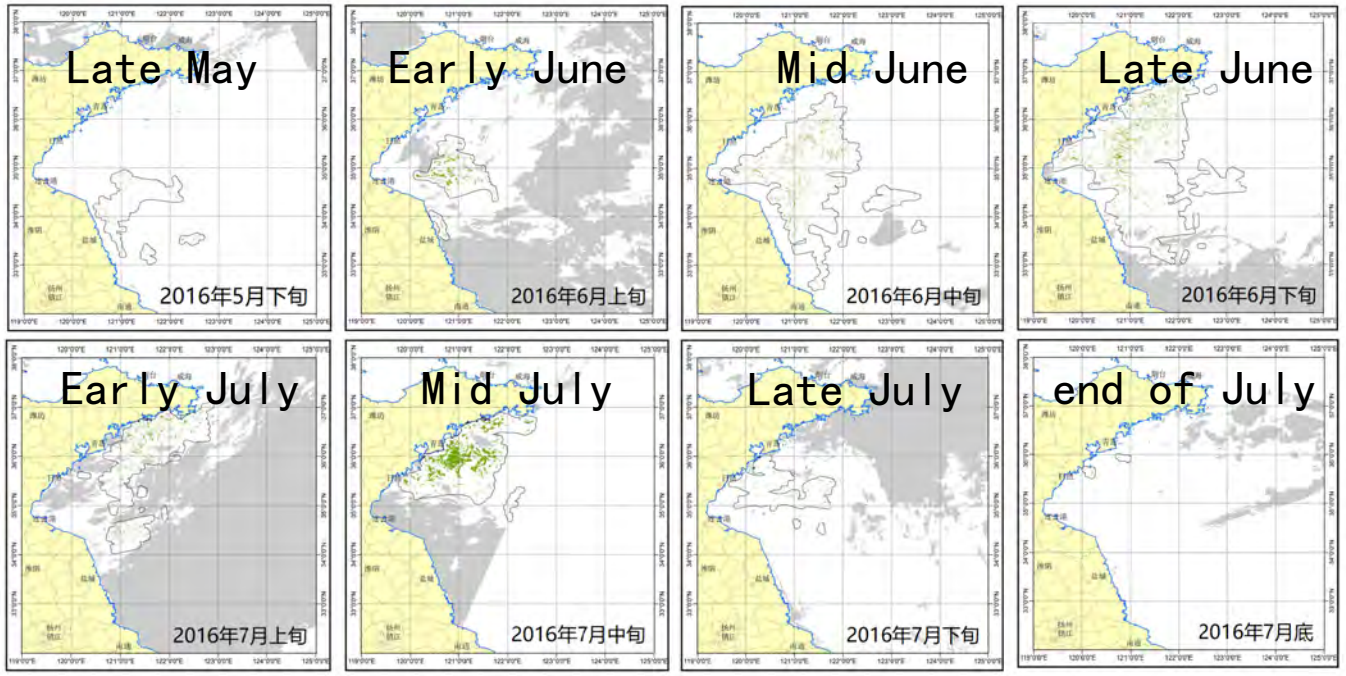
In July 2016, the coverage and distribution area of the green tide maintained a relatively high level in the middle and early stages, and gradually decreased in the later stages. In early July, green macroalgae gathered the Rizhao coast in large scale. In the middle of July, amounts of macroalgae broke out in the coastal waters of Qingdao, Shandong and Haiyang, Yantai. At the end of late July, green macroalgae began to weaken gradually, and there was no mass of macroalgae in coastal waters and banks, and green macroalgae gradually disappeared in August.

Spatial and temporal distribution of green tide particles and relative biomass in 2016

Spatial and temporal distribution of green tide particles and relative biomass in 2016

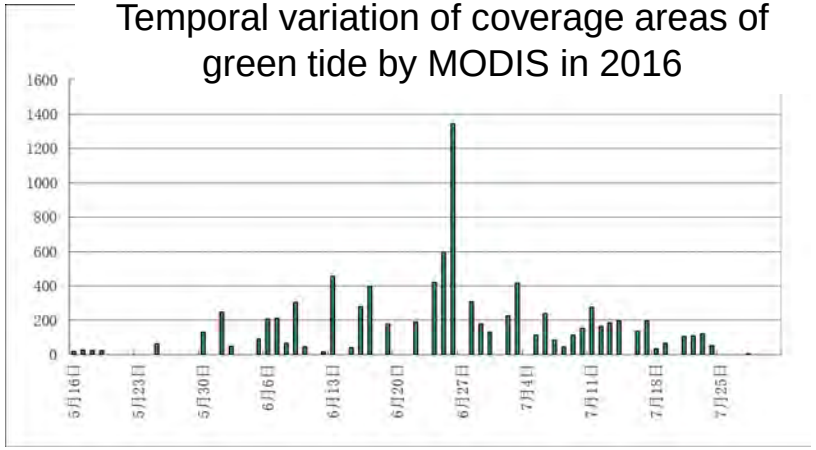


MODIS remote sensing data



- It began to grow rapidly and continuously in mid-May.
- The high level was maintained from early June to late July.
- At the end of July, it entered a fast decline period.
- It disappeared in early August.

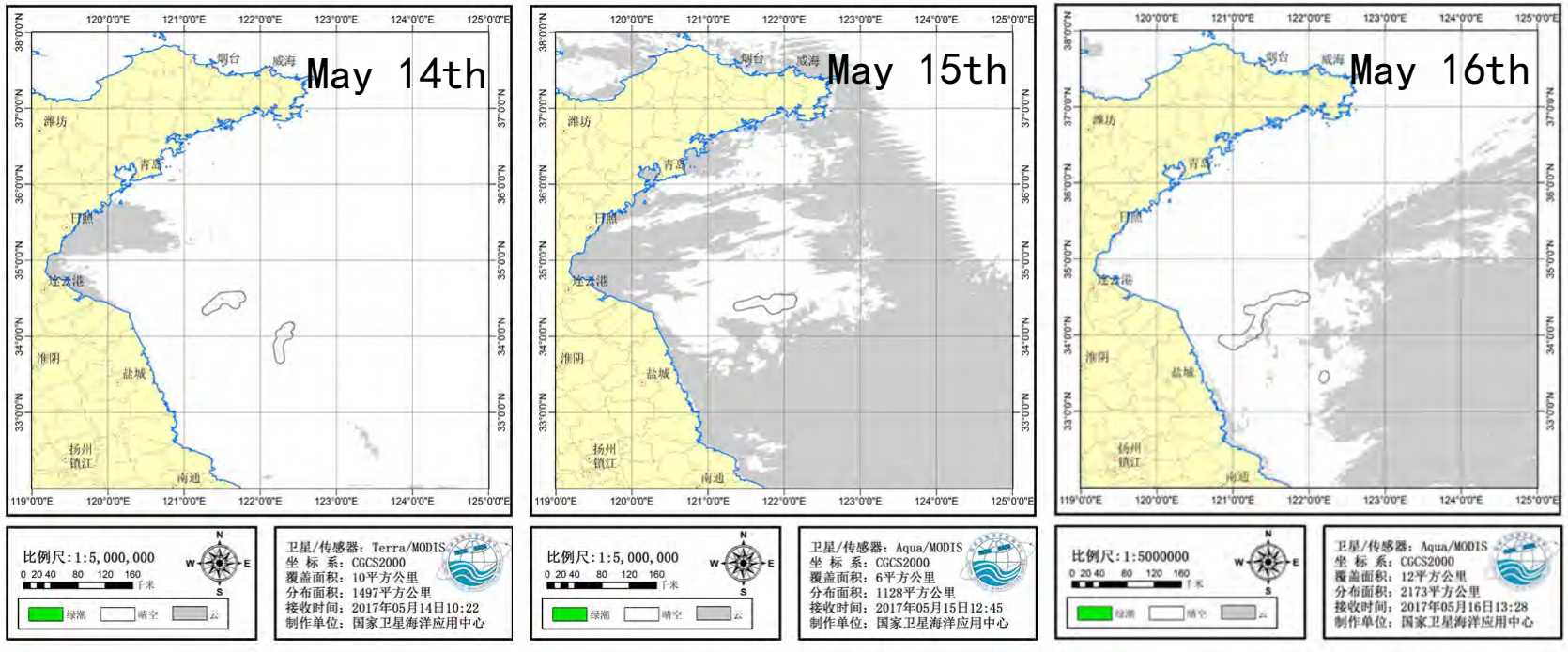
Temporal variation of coverage areas of green tide by MODIS in 2016



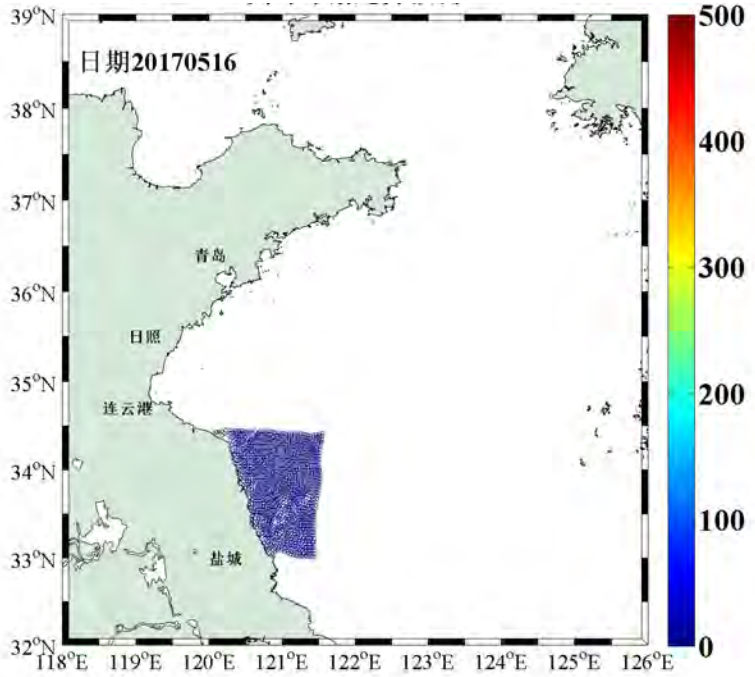
Numerical study and verification in 2017

In mid May 2017, near the eastern Yancheng coastal areas, the outbreak of green tide was monitored by MODIS, covering a total area of ten square kilometers, with an area of about 2200 square kilometers.

MODIS remote sensing data



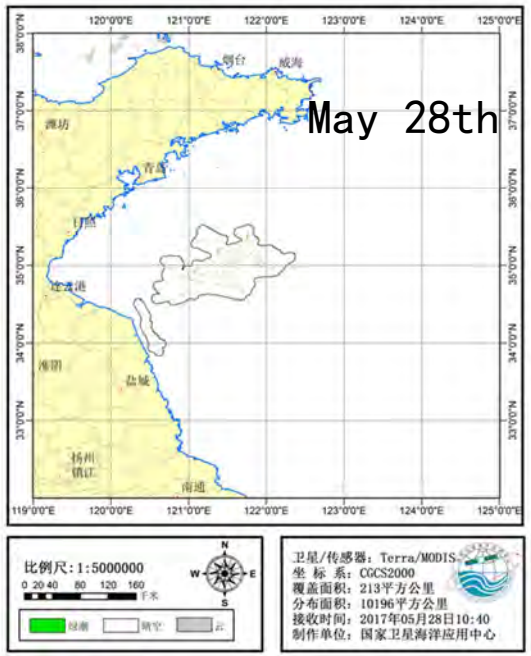
Eco-hydynamic Modeled data

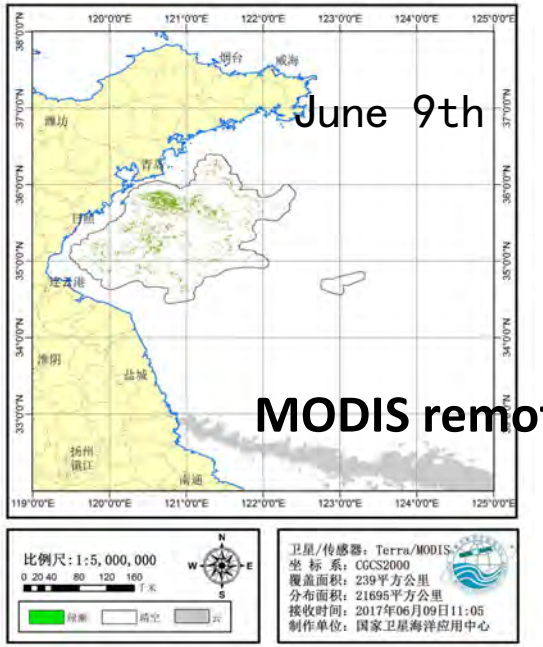


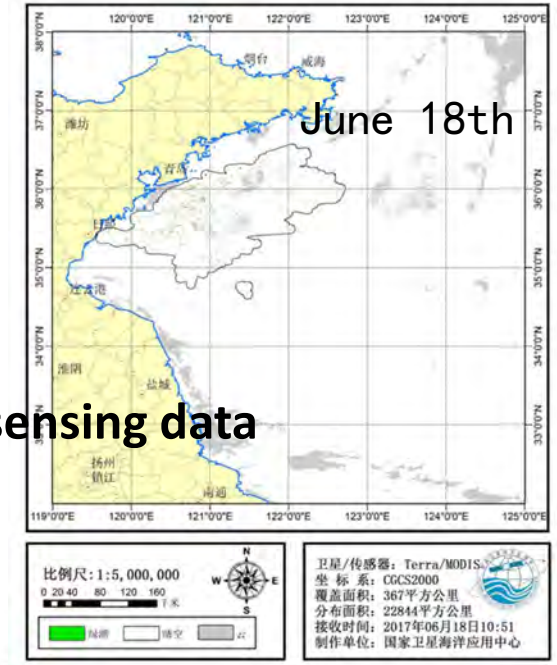
The model adopts the same parameters with 2016.

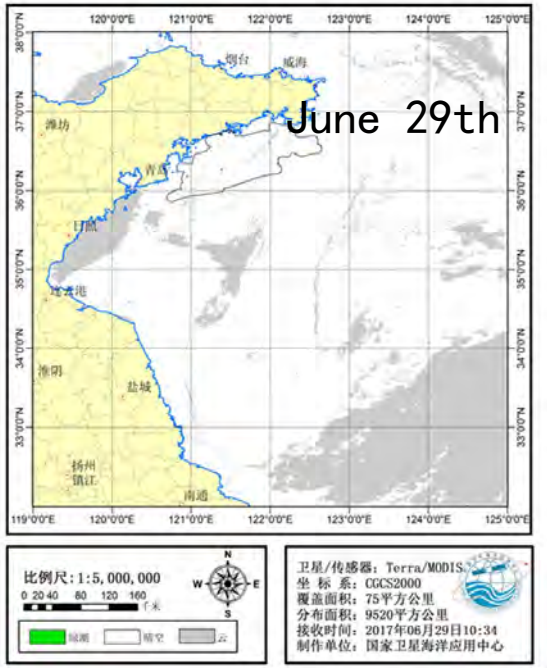
CFSR forcing：~0.25°，current、wind、light、temperature；Model：ROMS，resolution~3km；

Duration：5.15-8.31；Initial position： the eastern Yancheng (119.8-121.5; 33-34.5)；particles：1248

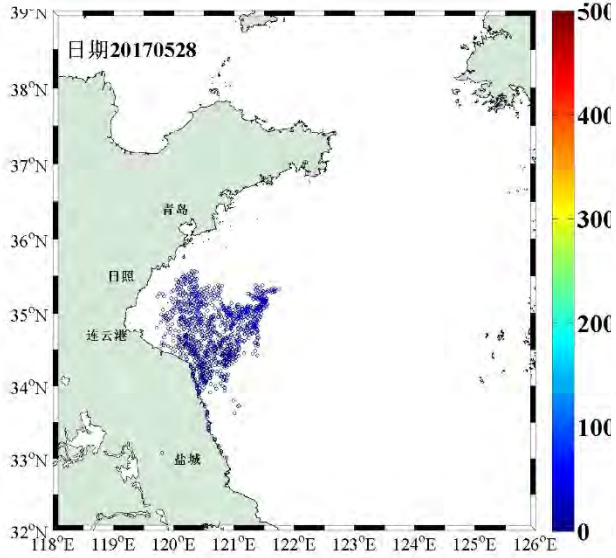


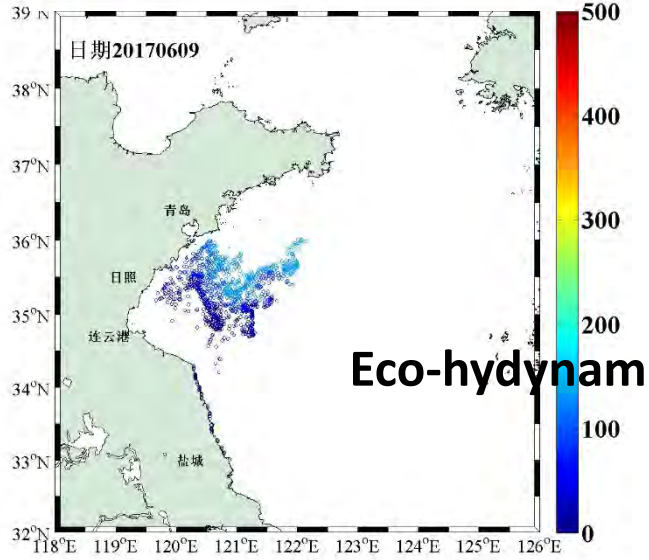


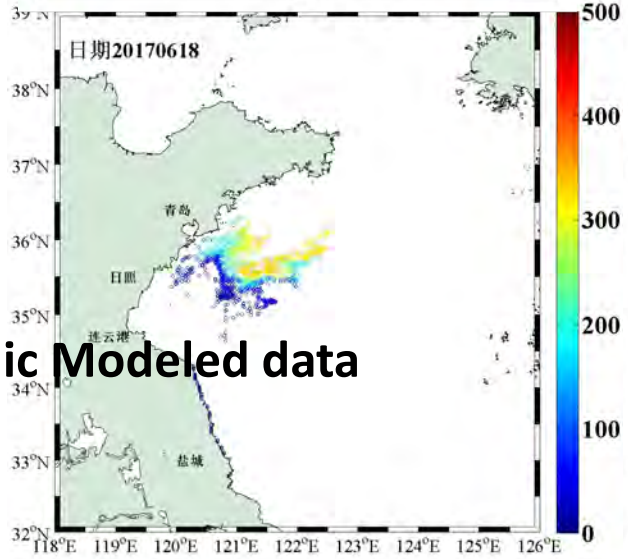


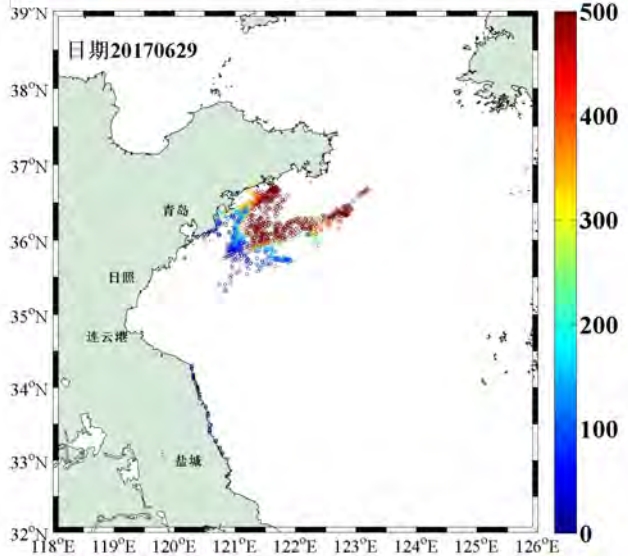


MODIS remote sensing data







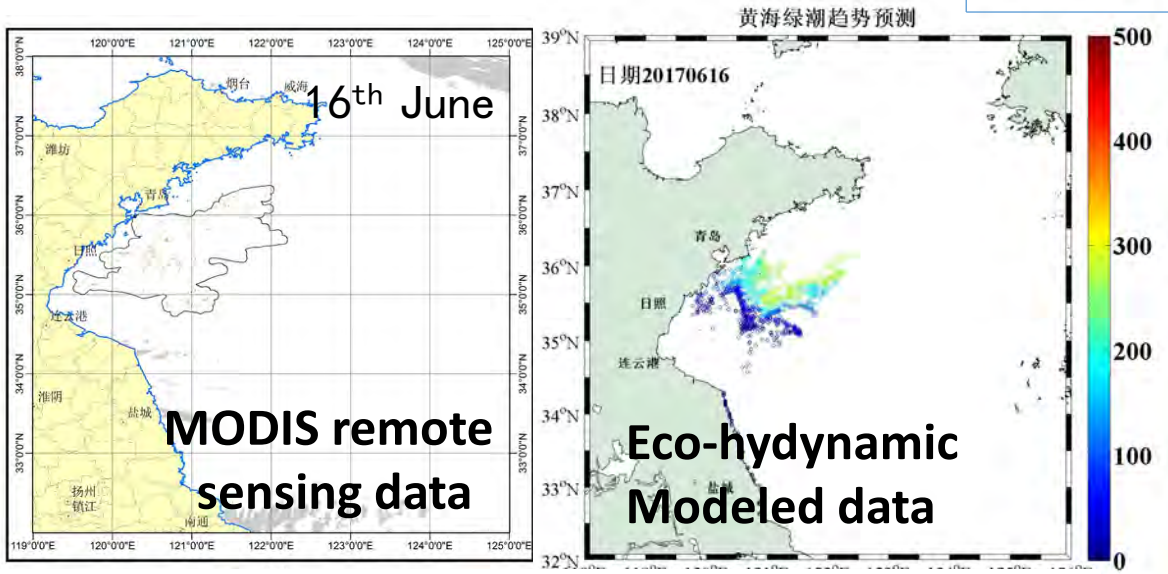


Eco-hydynamic Modeled data

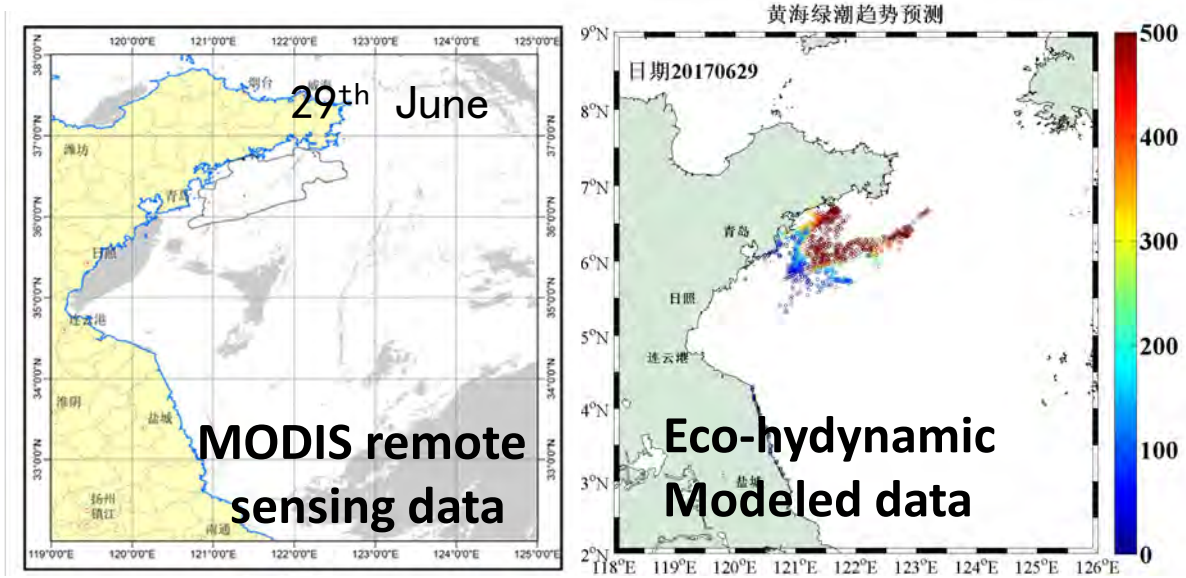
- The temporal and distribution of northward trajectories of green tide are in good agreement with the observed results. On June 8-9th, the amounts of macroalgae approached the coast of the Shandong peninsula. At the end of early June, a little macroalgae were found near Rizhao and Qingdao coast. In the middle of June, amounts of macroalgae gathered near Qingdao coast. In late June, green tide began to influence Haiyang Yantai, Rongcheng Weihai coastal areas successively.

June 16th 2017, Qingdao

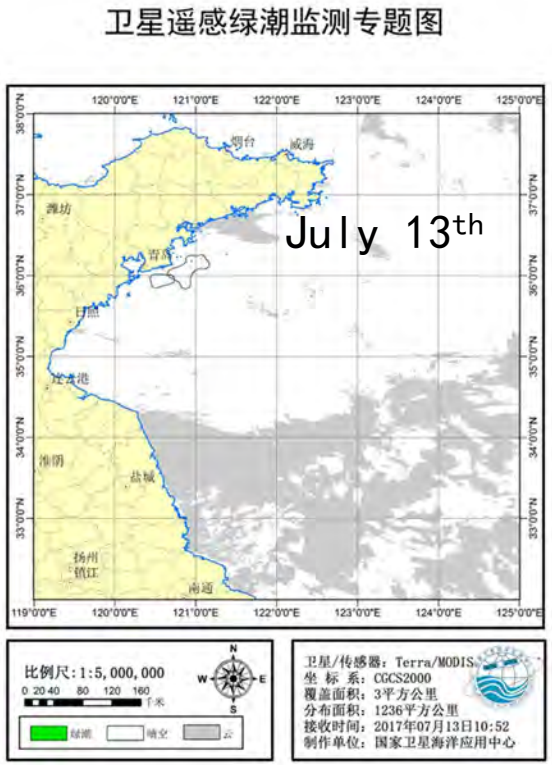
June 29th, 2017, left: Yantai, Haiyang; Right: Weihai, Rushan



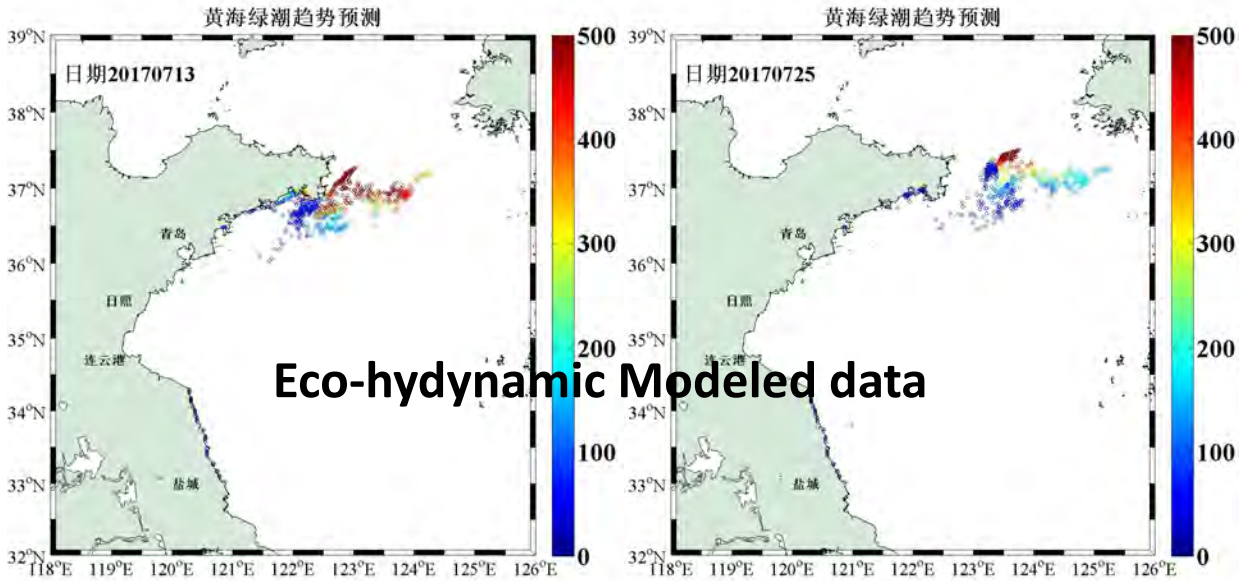
On June 11, Qingdao City launched the Class IV Early Warning and Emergency Response to green tide.



Green tide drift near Haiyang, Yantai coast on June 23; near Rushan, Weihai coast on June 29.

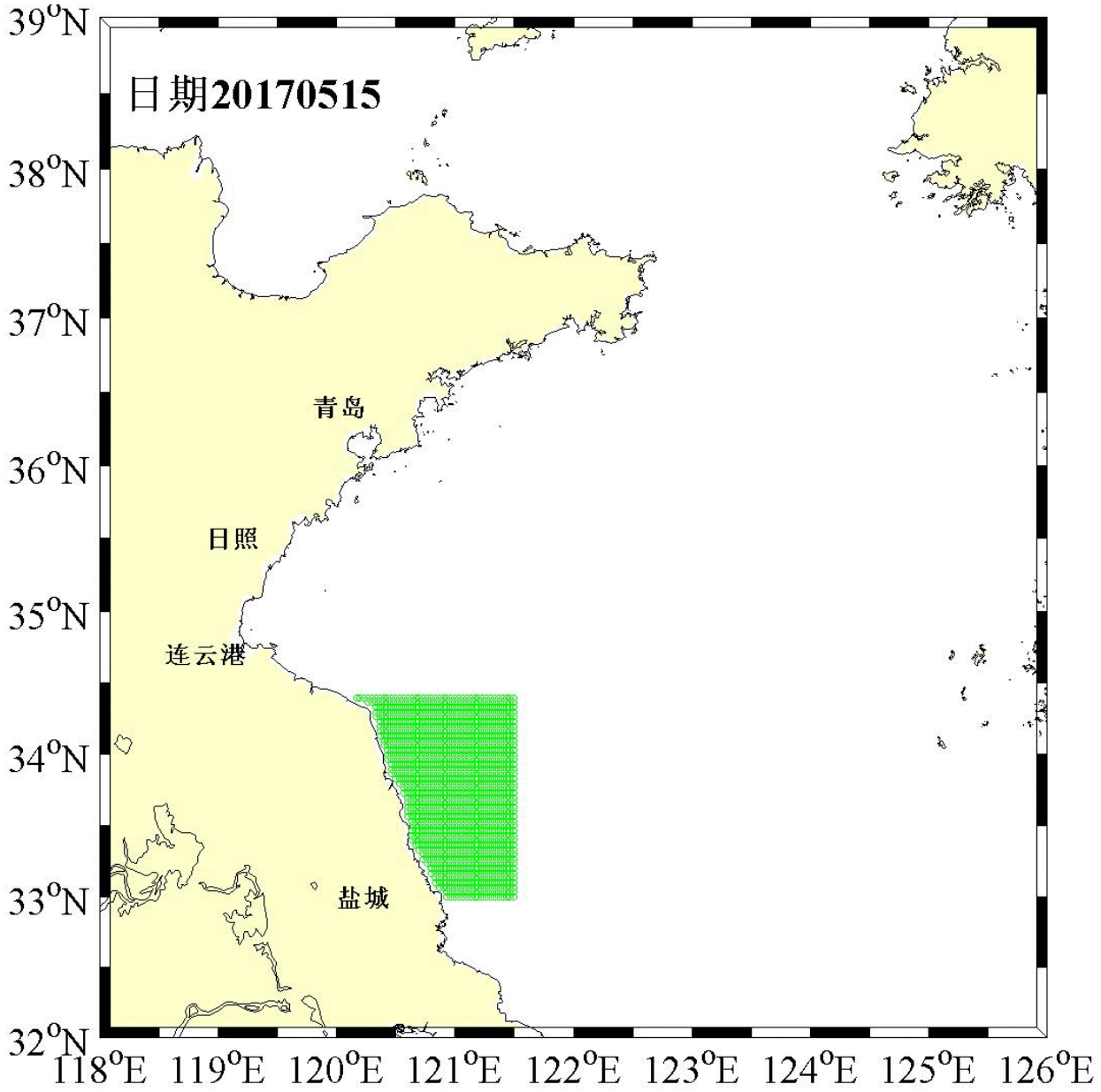


- In early July, amounts of green tide drifted near Yantai and Weihai coast. Distribution area and coverage area of green macroalgae decreased significantly.
- In mid-July, amounts of green tide gathered along the coast of Shandong Peninsula influenced by wind and current, and then began to wither away.
- Since July 14, it had not been monitored the pieces of green macroalgae by MODIS.
- In early July, it disappeared rapidly; in late July, it almost disappeared along the coast of Shandong Peninsula.

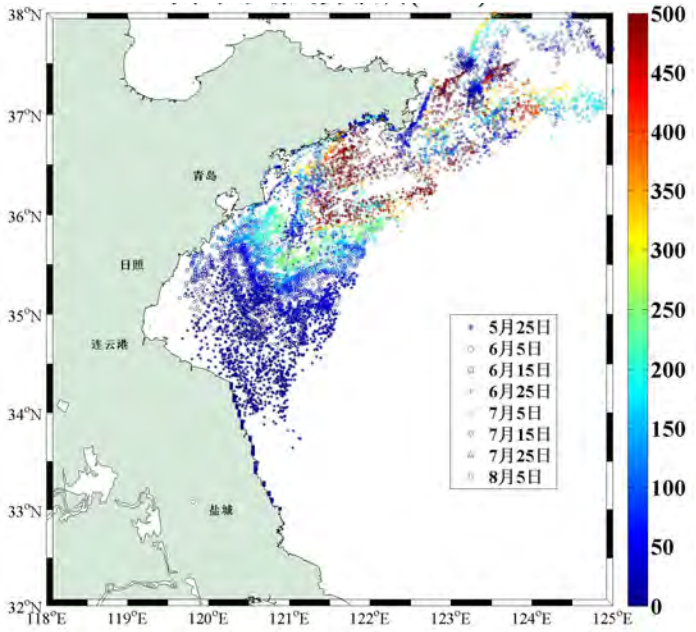


Eco-hydynamic Modeled data

Temporal and distribution of particle trajectories in 2017



Spatial and temporal distribution of green tide particles and relative biomass in 2017



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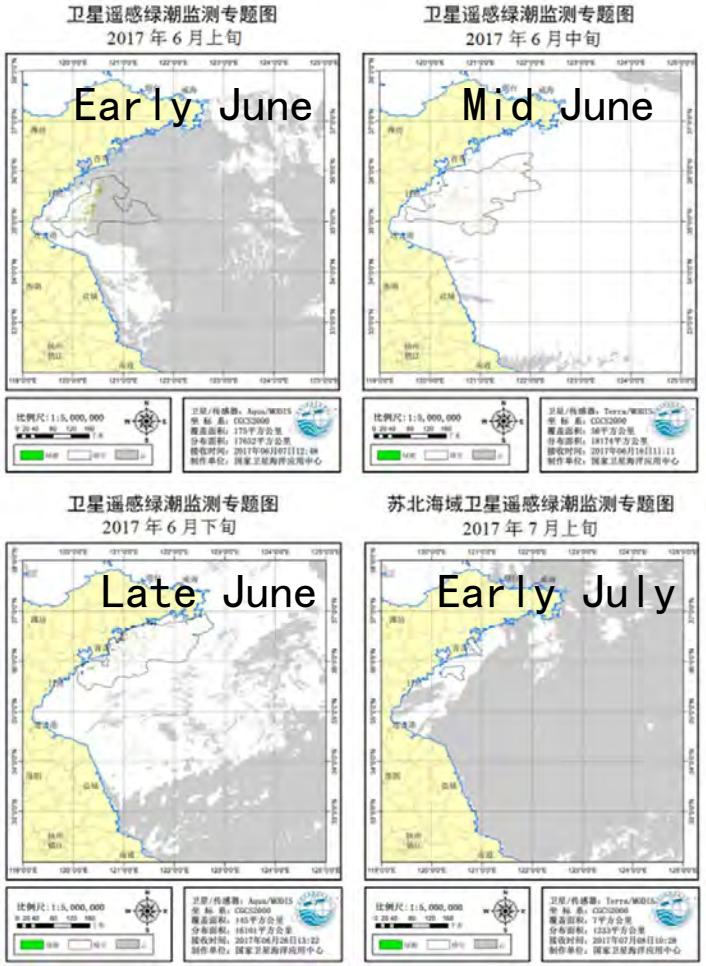
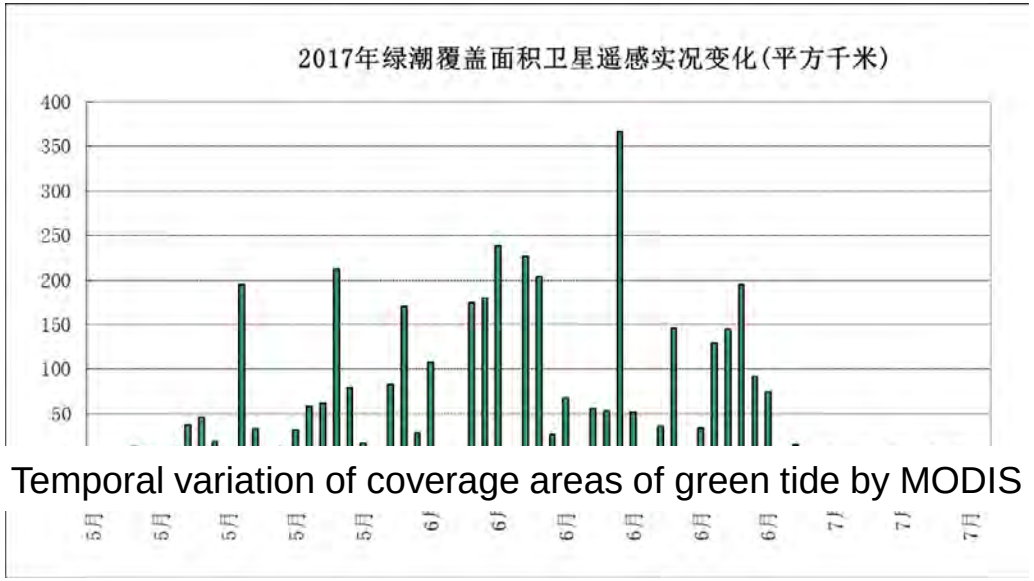


MODIS remote sensing data



Temporal variation of coverage areas of green tide by MODIS

- It began to grow rapidly and continuously in mid-May.
- The high level was maintained from late May to late June.
- In early July, it entered a fast decline period.
- It disappeared in mid-July.

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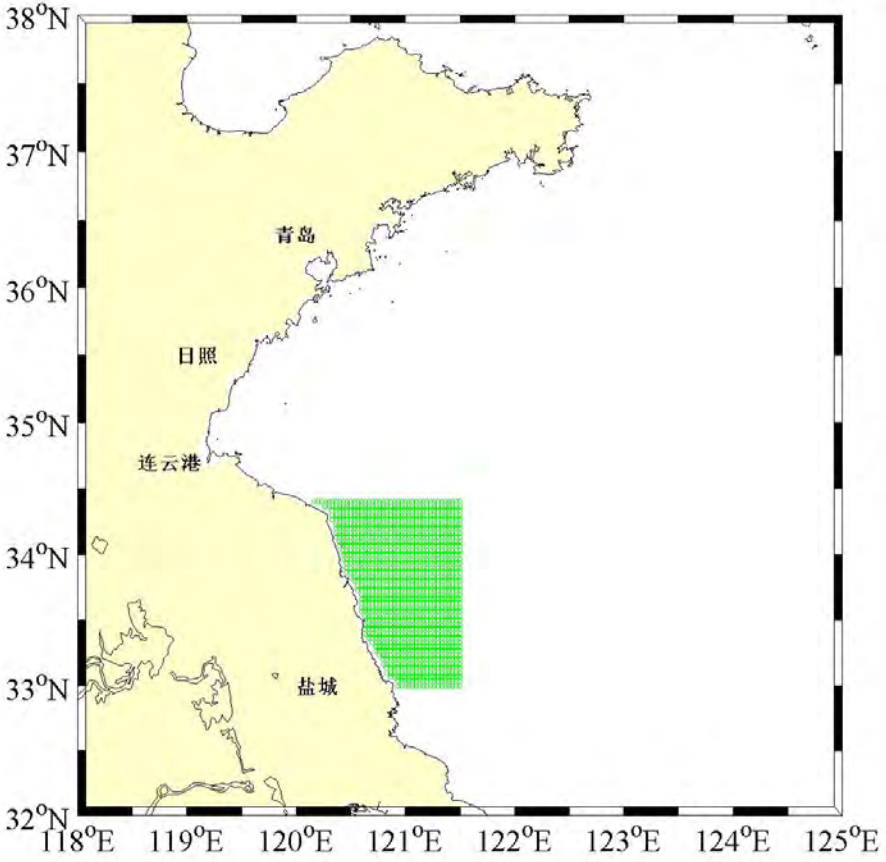
Prediction of green macroalgae in 2019

Temporal and distribution of particle trajectories in 2019



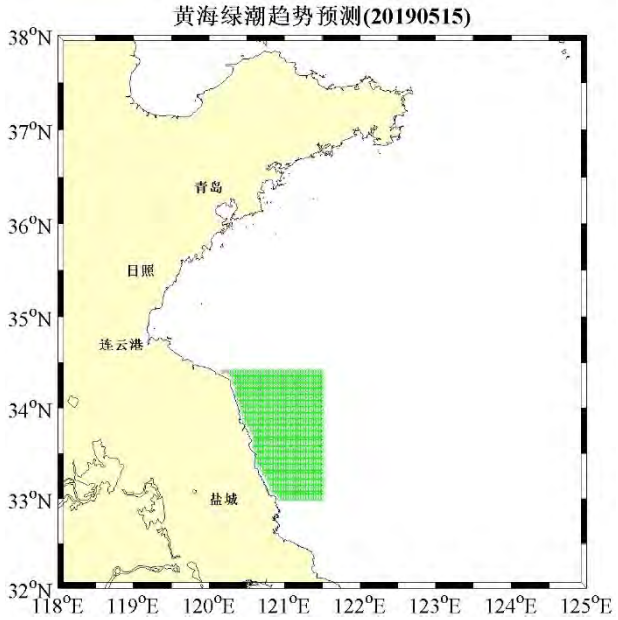
CFS forcing:

~1°, wind, current, light, temperature;

Duration: 5.15-8.31;

Initial position: the eastern Yancheng (119.8-121.5; 33-34.5);

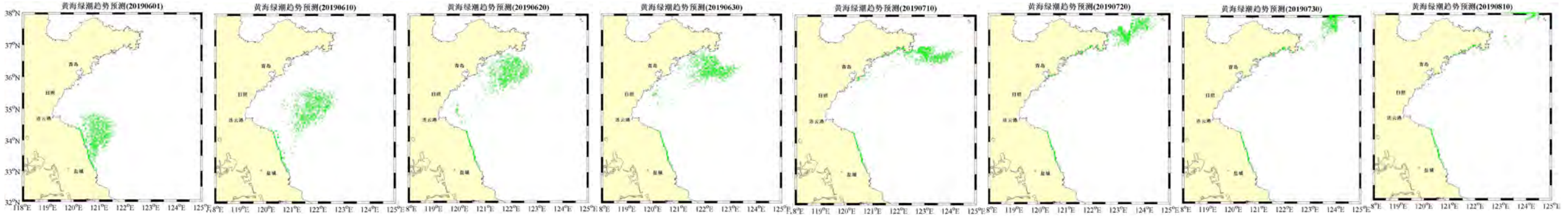
Particles num: 1248

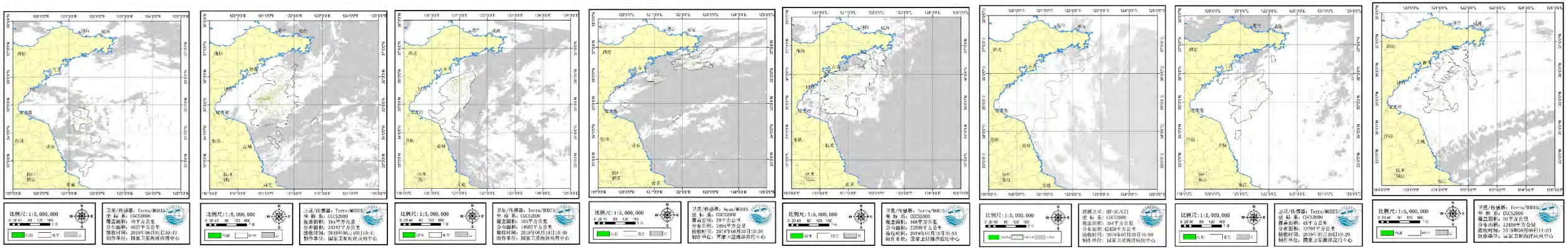


- It is expected that the green tide will outbreak and drift northward from the east of Yancheng, Jiangsu province in 2019. The results of the model showed that the green tide was mainly concentrated in the east of Yancheng coastal sea areas before June, and developed northward rapidly in the early June. During the period, the north and South movements were repeated by wind and current.
- In the late June and early July, the green macroalgae gathered near the southern coast of Shandong peninsula, including Qingdao, Yantai, Weihai.
- In the middle of July, with the mortality rate increasing and the growth rate restrained, the net growth rate of macroalgae was decreasing. Enteromorpha proliferata no longer grew and entered a period of extinction.
- From late July to early August, green tide disappeared in the Yellow sea.

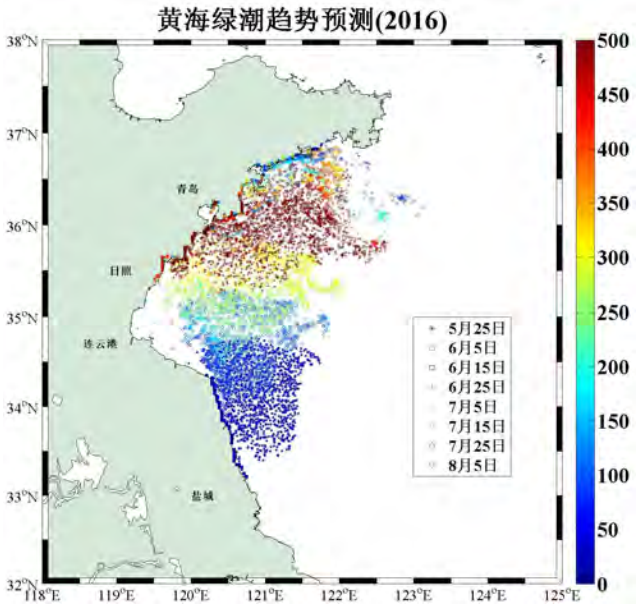
Prediction and analysis of green macroalgae in 2019

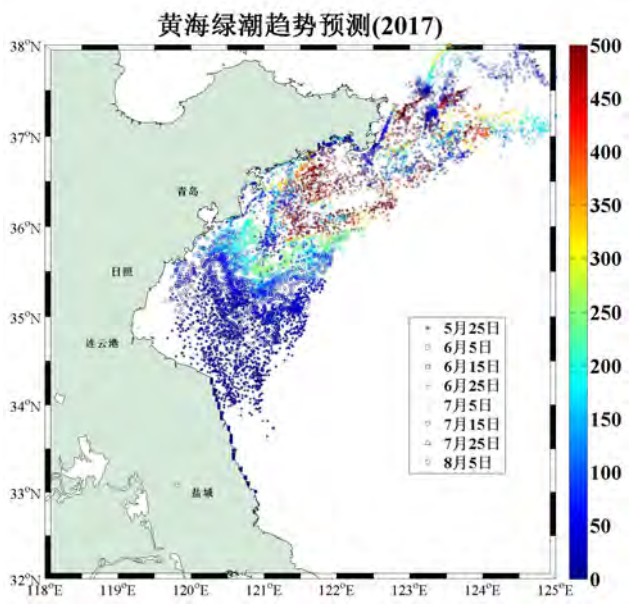
June 1st | June 10th | June 20th | June 30th | July 10th | July 20th | July 30th | August 10th

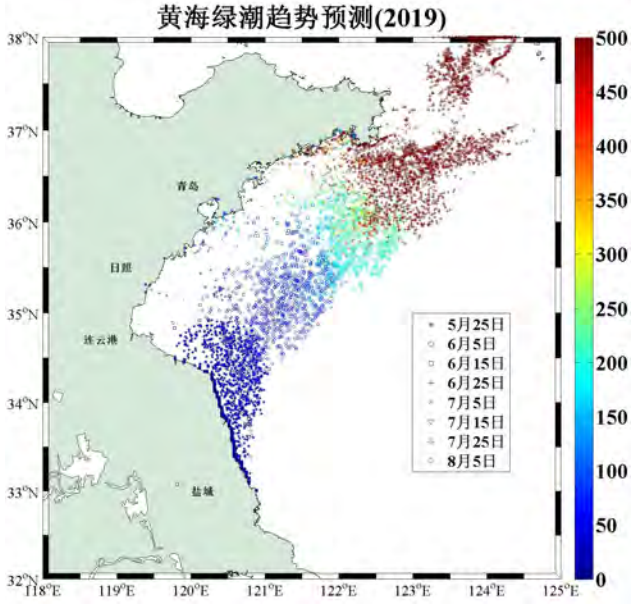


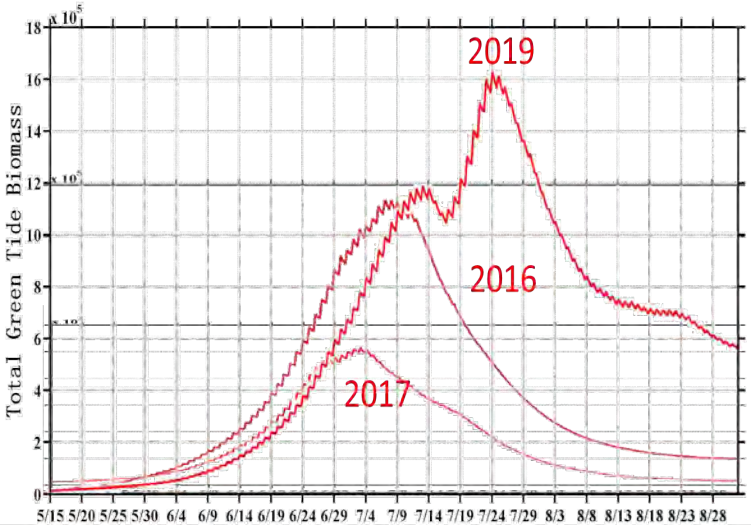


- Characteristics 1. Drifting path: the main body is in the south area of the Yellow Sea in the early stage and migrates to northeast in the middle and late stage, which is more eastern than that in previous years.
- Characteristics 2. Influencing shore: mainly for Qingdao, Weihai and Yantai.
- Characteristics 3. Influencing time: late June and early July.
- Characteristics 4. Disaster severity: mainly offshore of the northeast coast of the Shandong peninsula. The disaster may be relatively weak.
- Characteristics 5. Extinction time: late July.









✓Surface current and sea surface wind directly affect the migration path and range of green macroalgae, and so do the biomass of the green macroalgae.

Outline

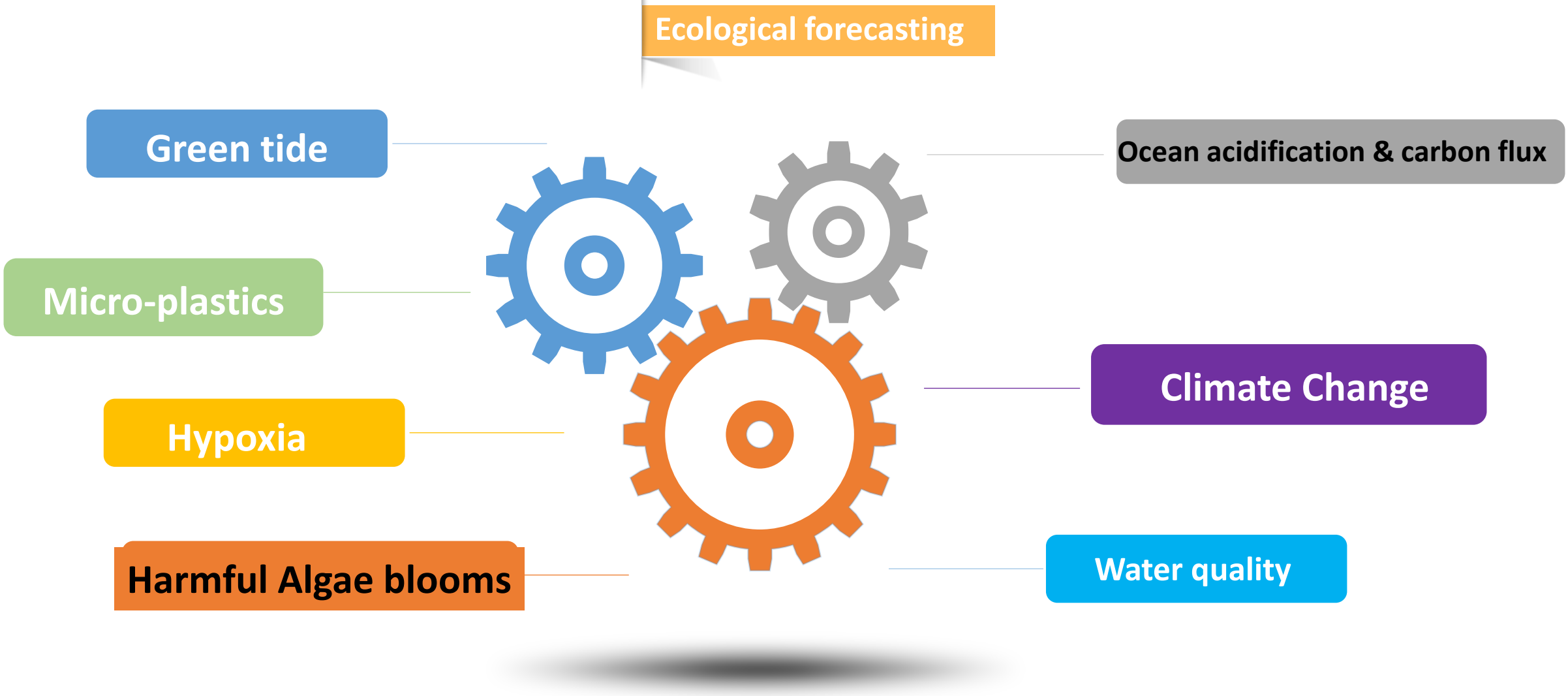
1. Historical analysis

2. Numerical study and verification in 2016/2017

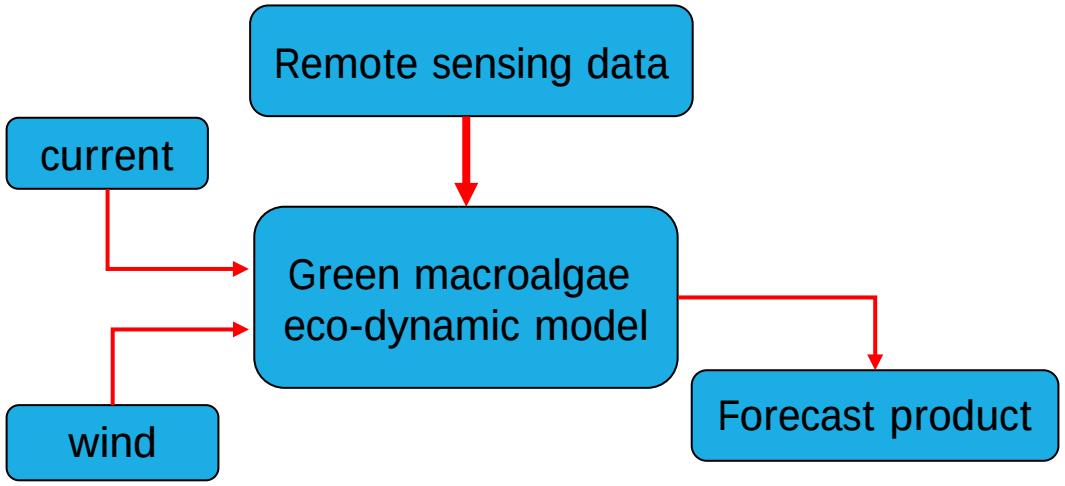
3. Prediction and analysis of green macroalgae in 2019

4. Operational ecological forecasting systems in China

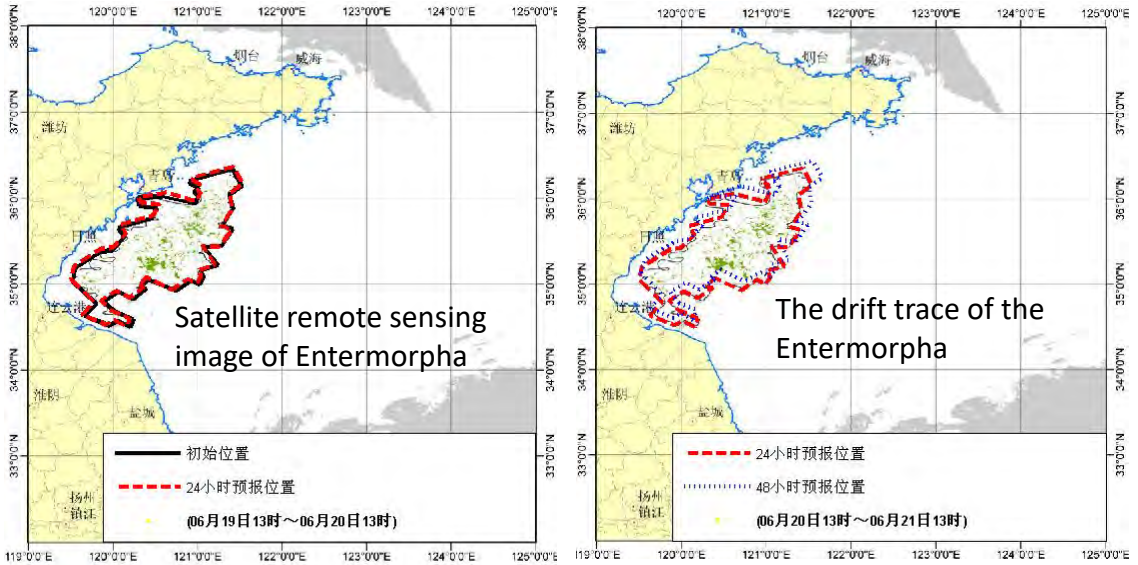
4. Operatinal ecological forecasting systems in China



Operational forecasting of green macroalgae system

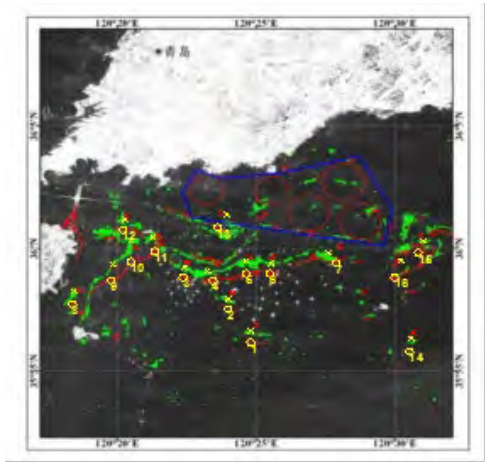


Operational forecasting of green macroalgae



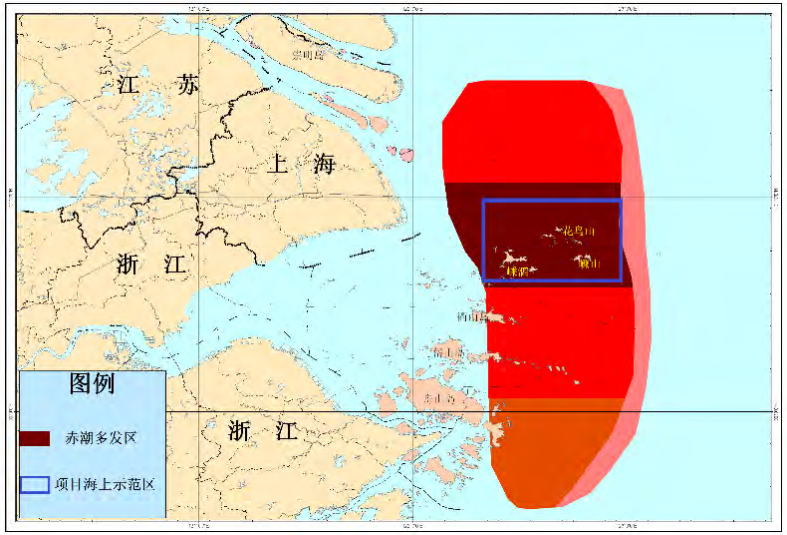
24/48-hour predicting drift regions of Green Tide (Entermorpha) in the Yellow Sea

Data :
COSMO-1 SAR
COSMO-2 SAR



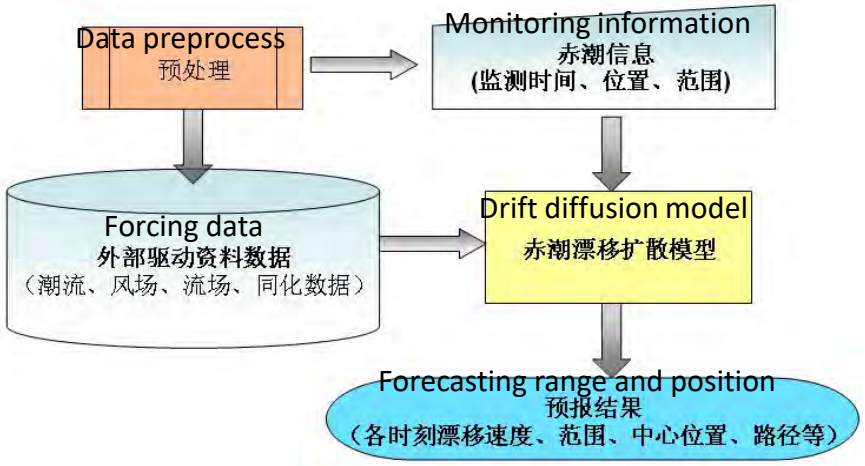
Data	Angle RMSE	Angle MAE	Speed RMSE	Speed MAE
2008. 7. 10	16°	11°	0.3km/h	0.3km/h
2008. 7. 22	16°	14°	0.2km/h	0.1km/h
2008. 7. 29	11°	7°	0.7km/h	0.5km/h

Forecast of Harmful Algae blooms

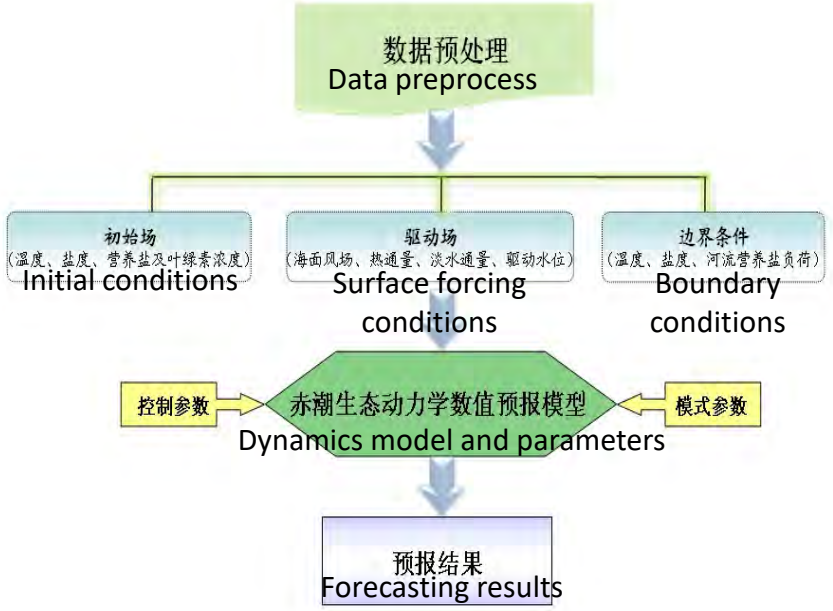


Demonstration area showed in the blue box in the East China Sea

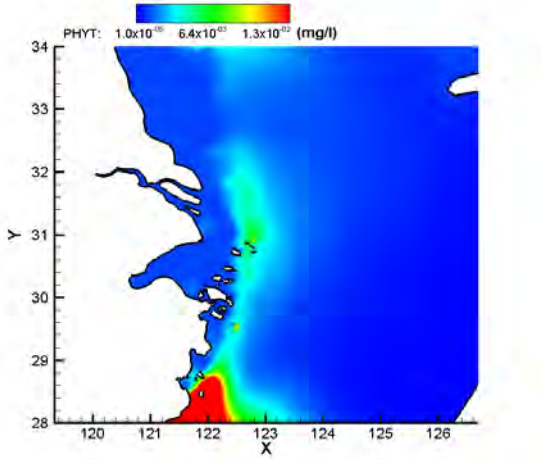
- **Operational forecasting system of HABs in demonstration area：**
- The products and reports of drift diffusion numerical forecasting and ecosystem dynamics forecasting are released about harmful algae blooms near the Yangtze River estuary.



Drift diffusion numerical forecasting system



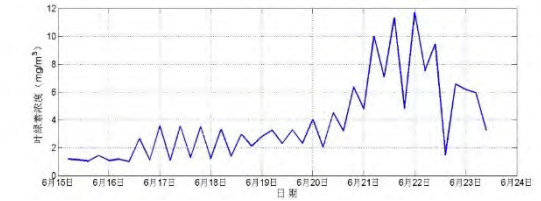
Ecosystem dynamics forecasting system



Chlorophyll-a modeled results

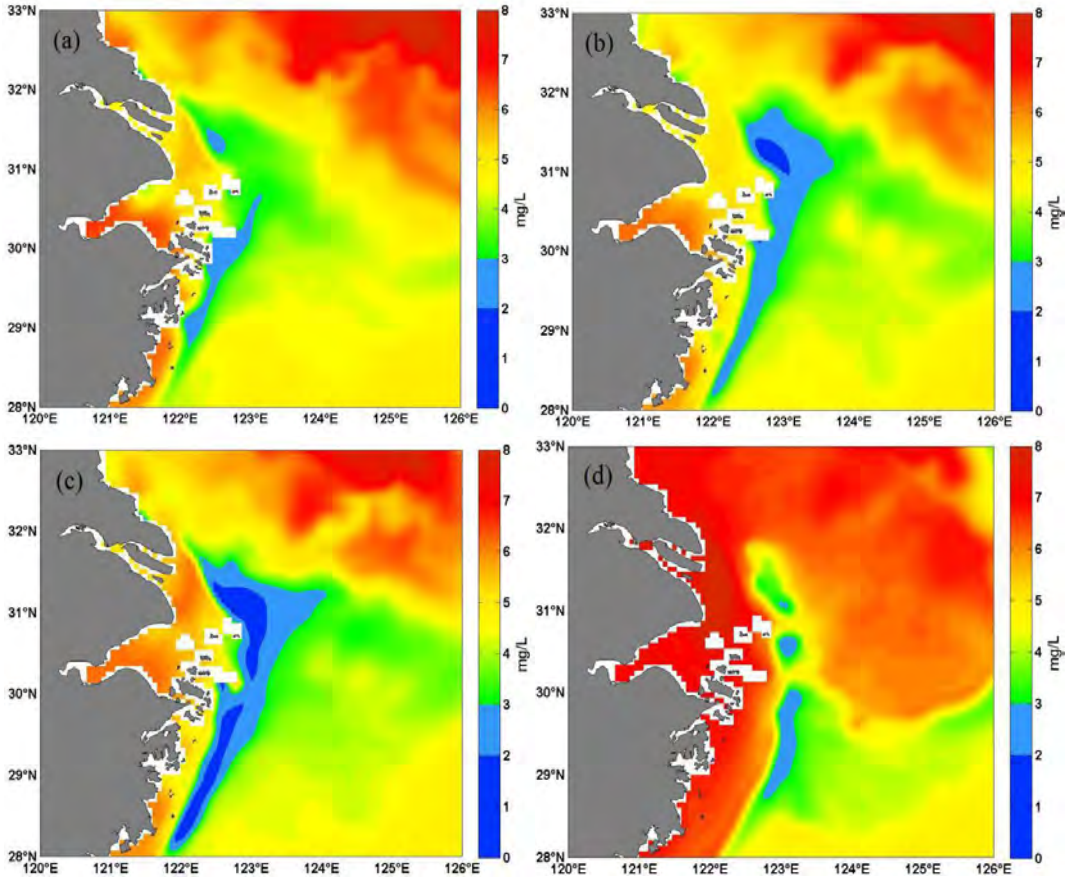
The chlorophyll concentration (Ai) when HABs occurs，
In case of :

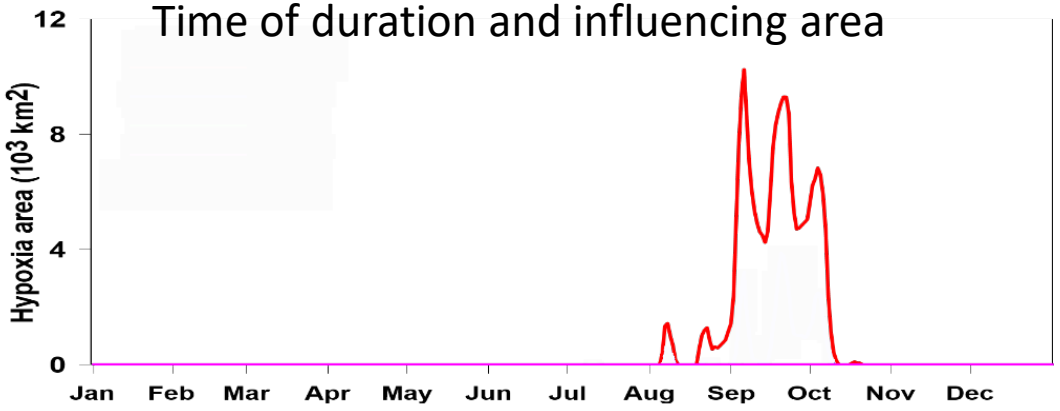
$$f_i = \begin{cases} 1 & A_i > a_1 \\ \dfrac{A_i - a_0}{a_1 - a_0} & a_0 < Ai < a_1 \\ 0 & A_i < a_0 \end{cases}$$

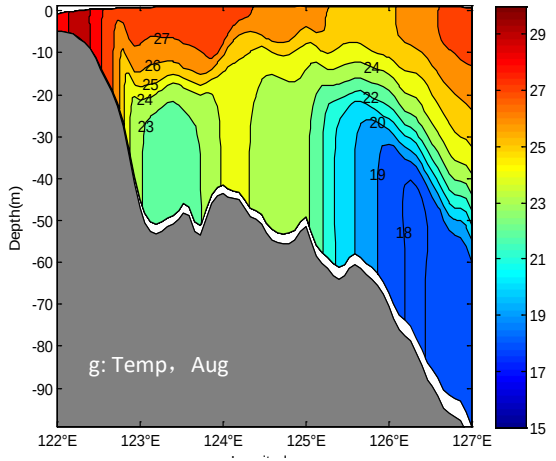


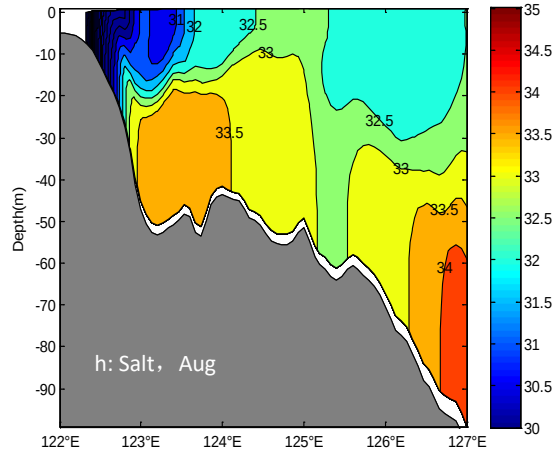
HABs occurrence probability

Forecast of Marine hypoxia





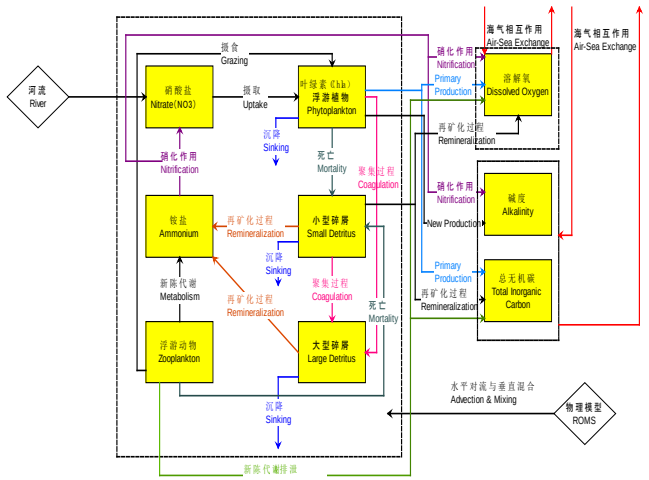


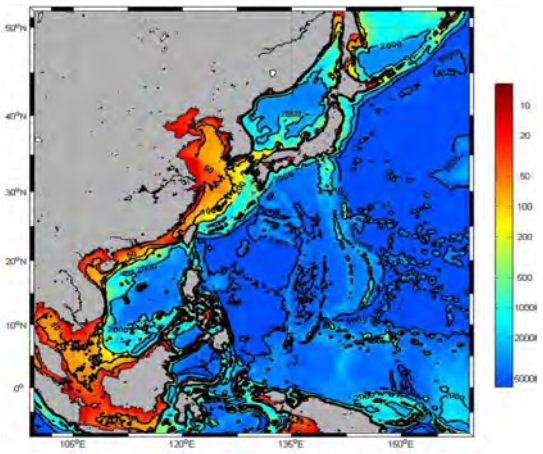


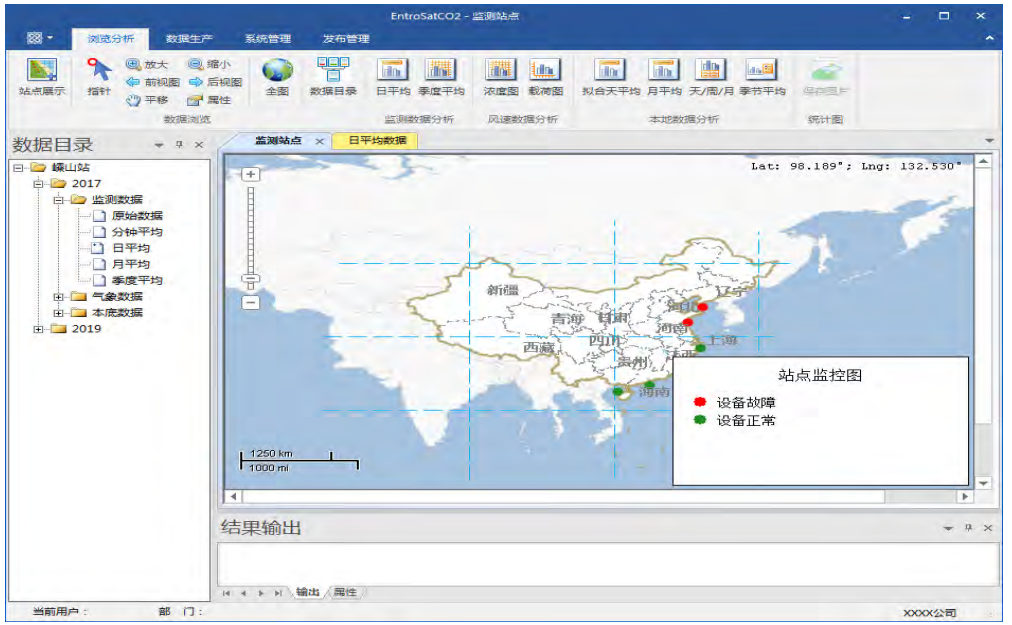
Hypoxia: Concentrations of dissolved oxygen below 2-3 mgO_2/l are a general threshold value for hypoxia for marine and estuarine organisms. (Vaquer-Sunyer and Duarte, 2008)

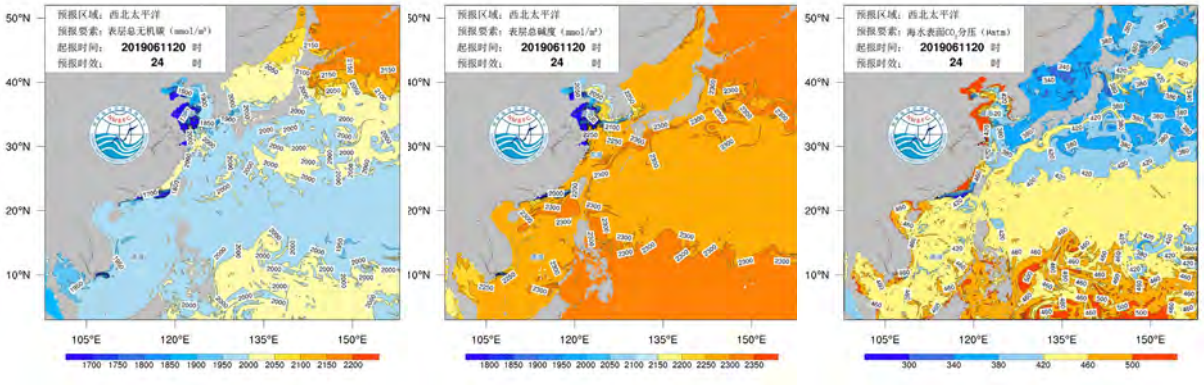
- ✓ Marine ecological modelling & forecasting
- ✓ Time of duration and influencing area of hypoxia
- ✓ Providing service guarantee for hypoxic effects in mariculture

Ocean acidification & carbon flux

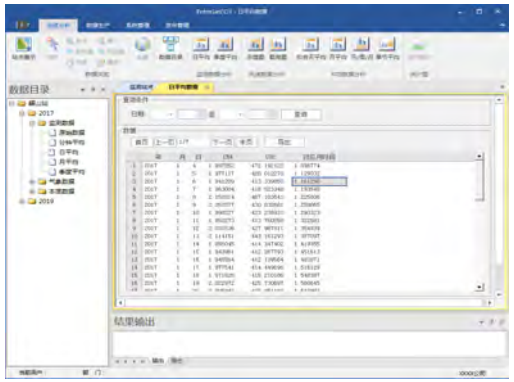


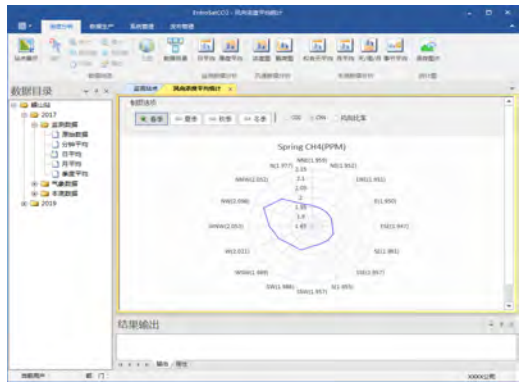






✓ Ocean Atmospheric Carbon Dioxide Concentration Monitoring Visualization System





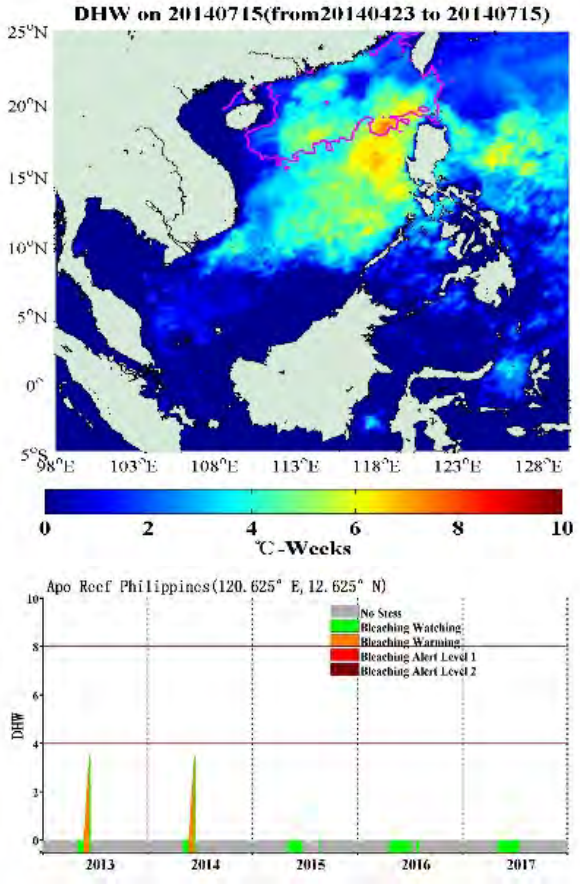
Data browse

Data analyze

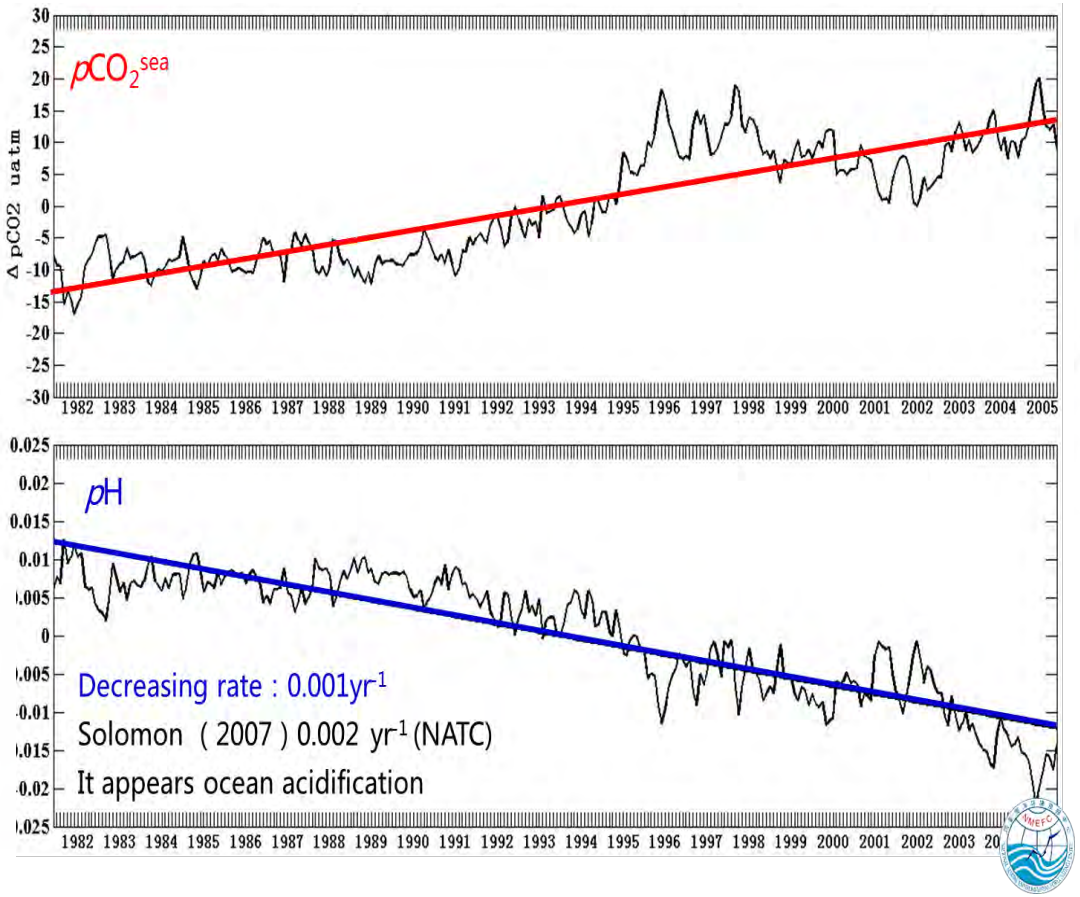
✓Marine ecological modelling & forecasting
✓Forecast of Total Alkalinity, Total Inorganic Carbon and pCO_2
✓Long-term trend of Ocean acidification

In the further : Multiscale forecasting of marine ecological environments and disasters

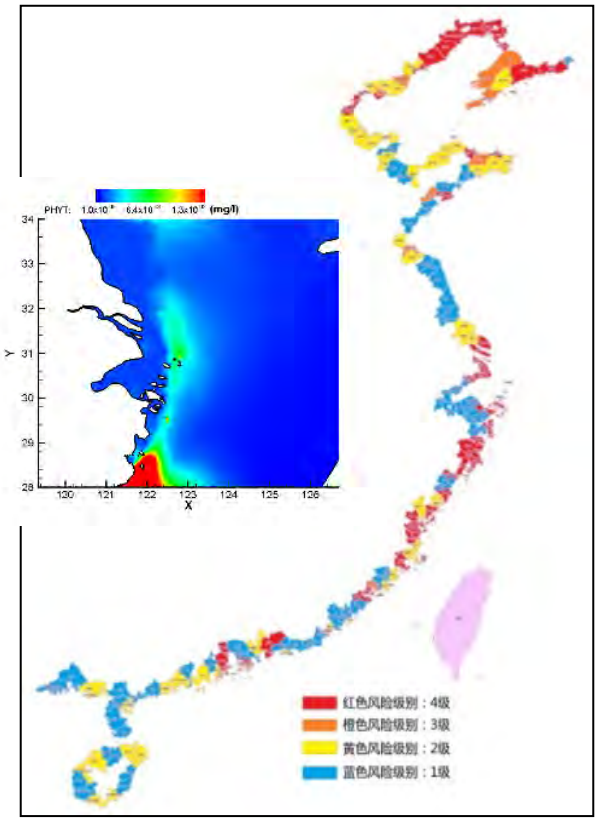
- Early warning
- Long-term prediction
- Risk assessment



coral bleaching



ocean acidification



Harmful Algae blooms

New Challenge

- To develop a new large-scale super-computing platform with multi-disciplinary integration of ocean, atmosphere and biogeochemical model.
- To apply advanced technology such as supper data analysis, scientific engineering computing and artificial intelligence.

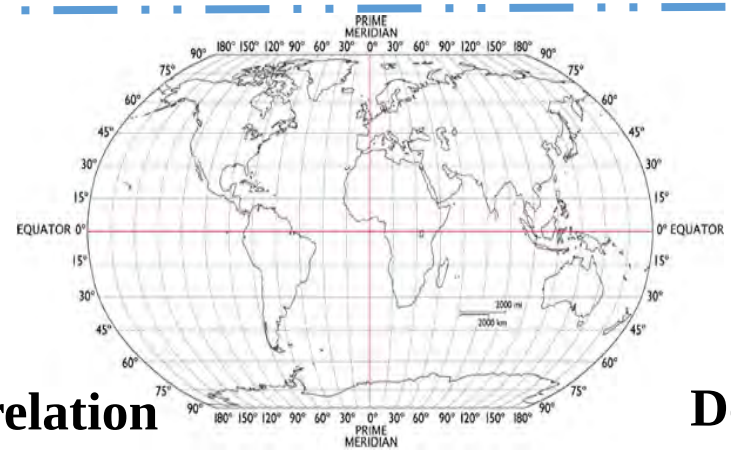
New Challenge

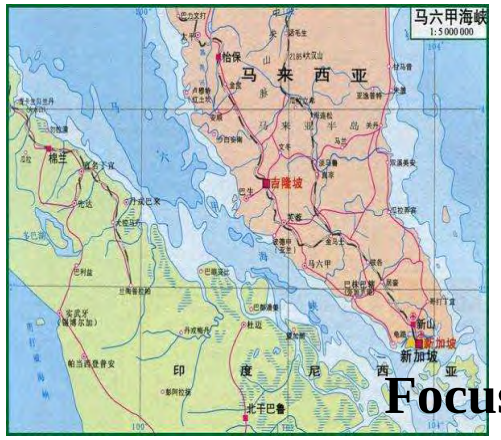
History Forecasting Data

F_{-60} F_{-59} F_{-58} ..... F_{-2} F_{-1}

History Observational Data

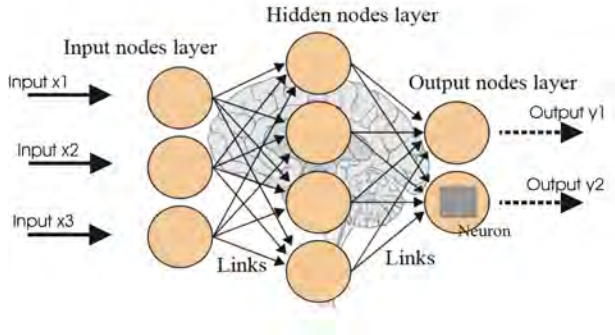
O_{-60} O_{-59} O_{-58} ..... O_{-2} O_{-1}





Correlation **Downscaling** **Focus region**

Neural Networks



Deep learning

Thank you for your listening!