

Digital Twins of the Ocean and its applications

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Professor Emeritus, University of Maine

Outline

1. Challenges of ocean and UN Decade
2. Digital Twins of the Ocean (DITTO)
3. A few examples
4. Some final thoughts

Coastal and Marine Ecosystem Stressors

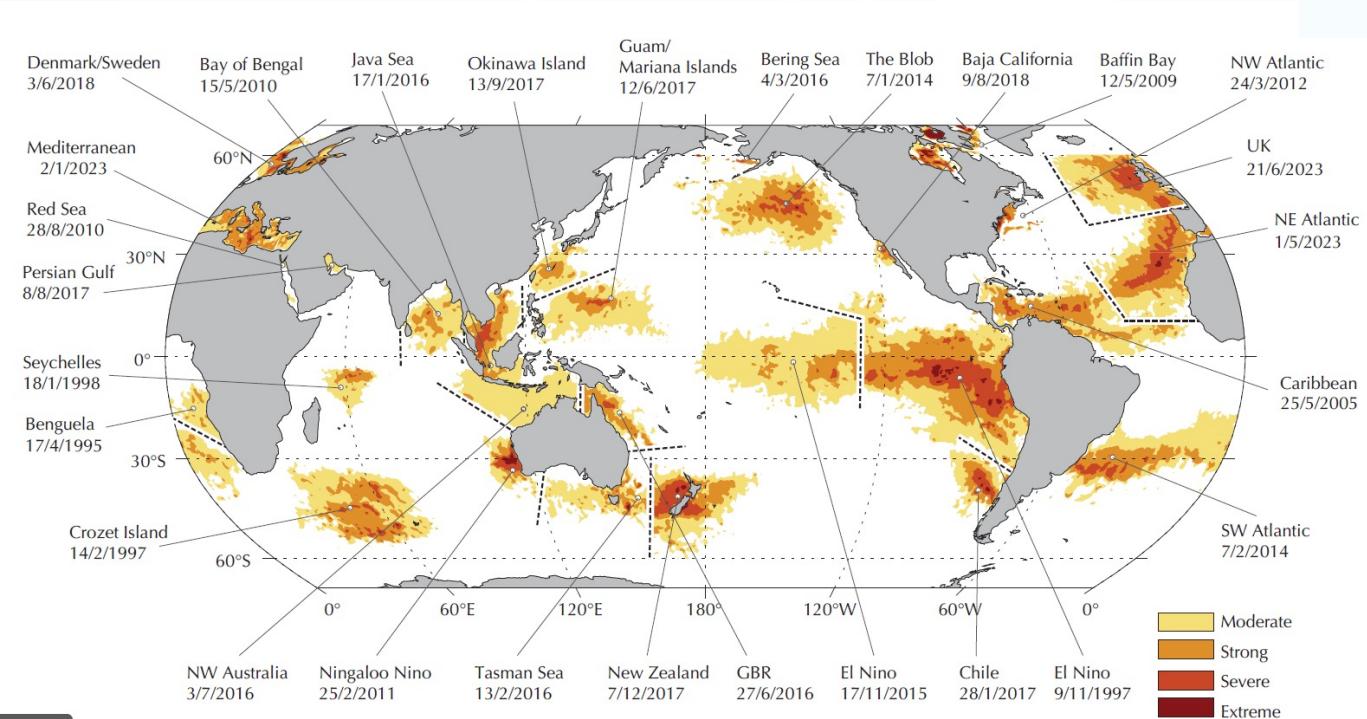
Climate Change

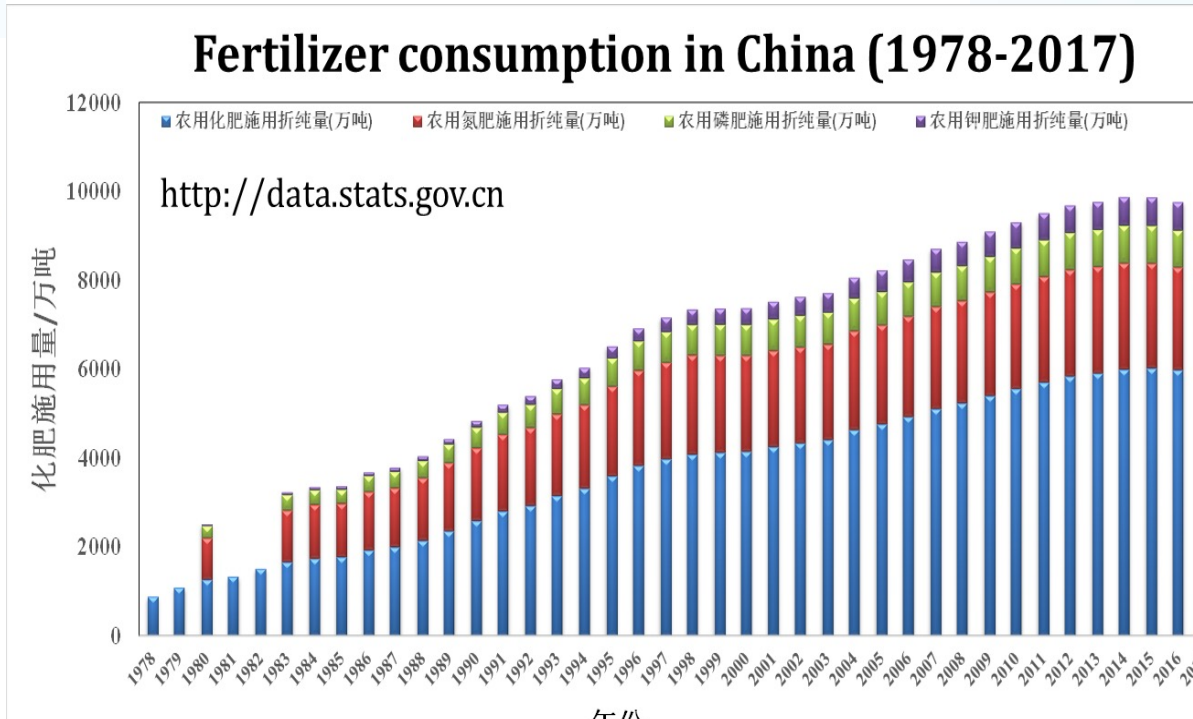
- Global warming
- Precipitation & runoff
- Sea-level rise
- Storms & extreme events
- Ocean acidification

Non-Climate

- Overfishing
- Eutrophication
- Loss of habitats
- Oil spill
- Land reclamation

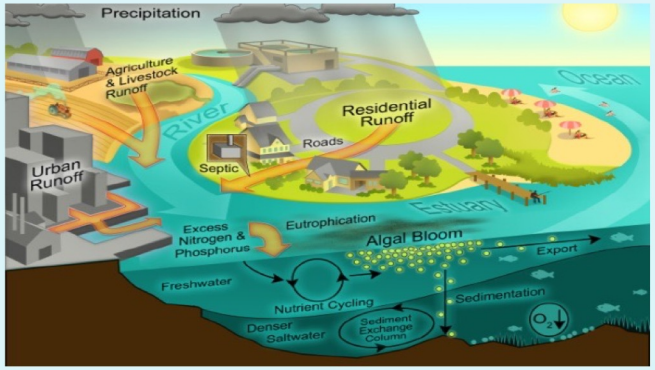
Marine Heatwaves





Coastal ecosystem hazards:
Large scale, wide influence and hard to restore

Eutrophication



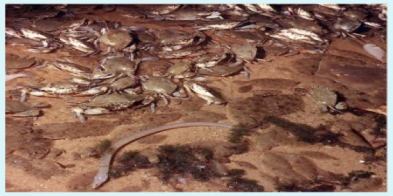
- Acidification



- Algal bloom



- Hypoxia



- Red tide



Pollution

- Heavy metal



- Petroleum



- Persistent Organic Pollutants



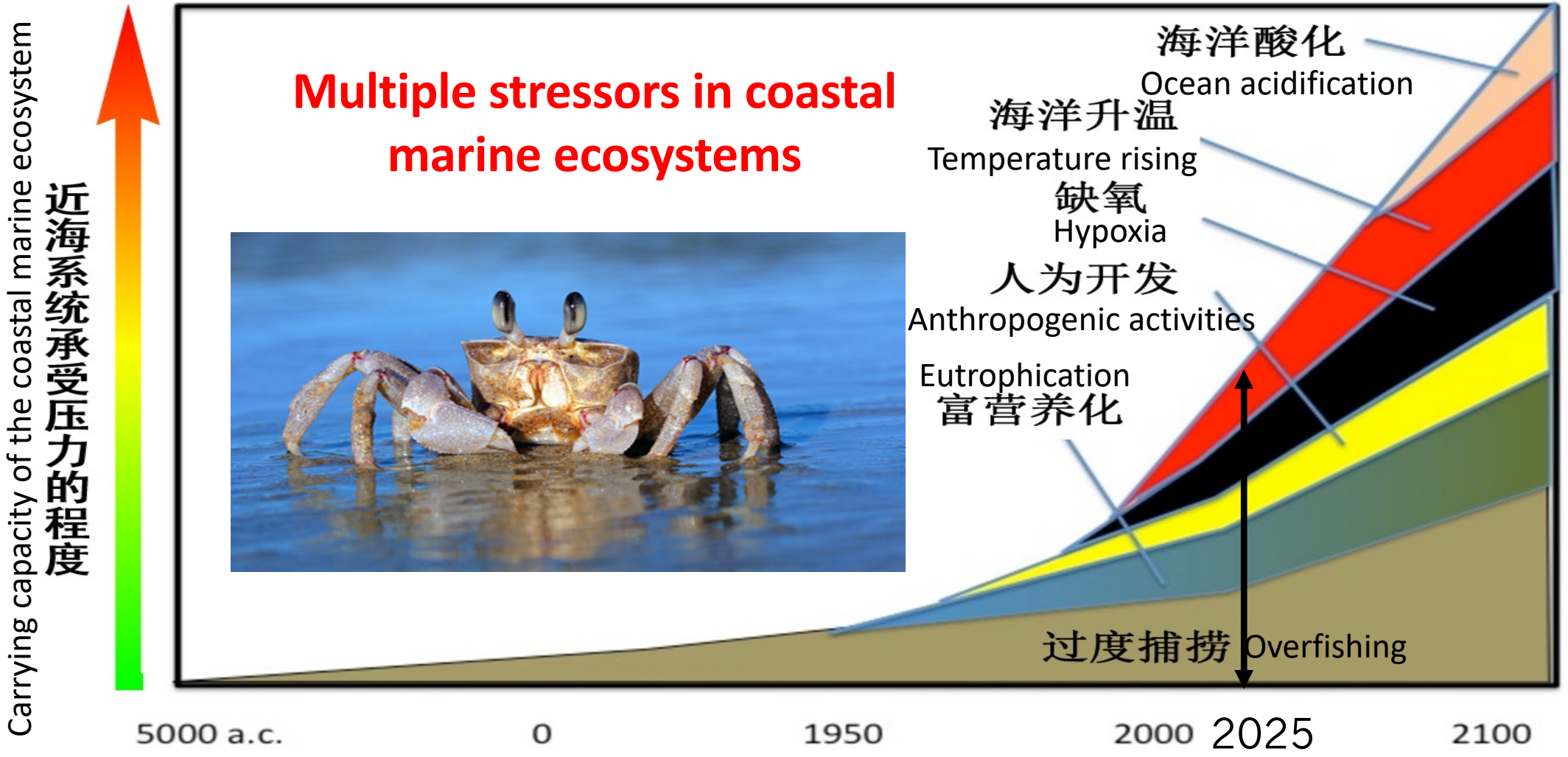
Over aquaculture



Fishery resources degradation



Future trends of ecosystem disasters in coastal area



UN Decade of Ocean Science for Sustainable Development (2021-2030)

科学至实、海洋可期

"The Science We Need for the Ocean We Want"



10 Years. 10 Challenges. 1 Ocean.

The Ocean holds the keys to an equitable and sustainable planet.

Join the revolution to unlock innovative ocean science solutions

DITTO and the UN Ocean Decade

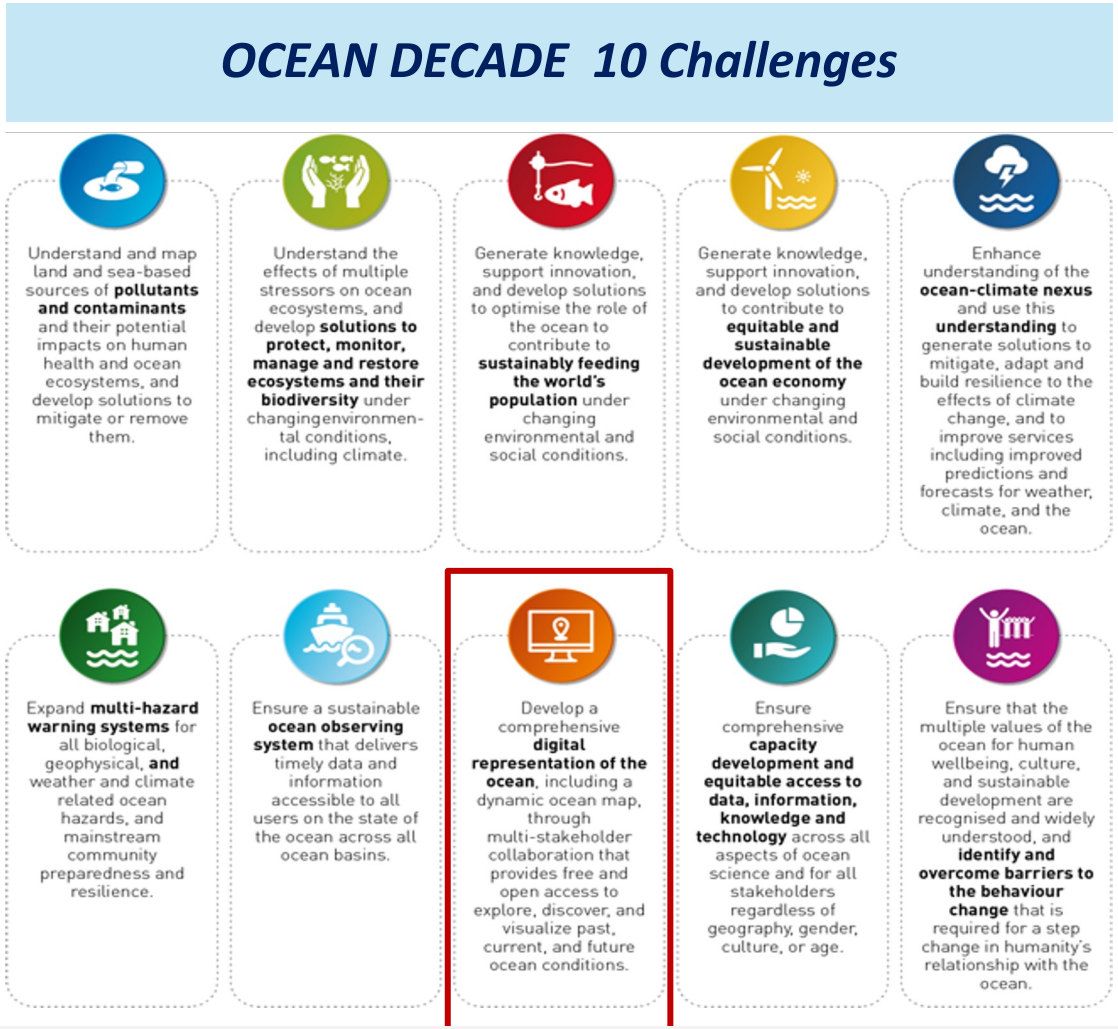
The science we need for the ocean we want

Challenge 8:

Create a complete digital representation of the ocean – a dynamic ocean map, free and open to all, showing past, present and future ocean conditions.

Marine Knowledge at Fingertips of our Communities:

Designing Digital Twins of the Ocean.



Digital Twins of the Ocean - DITTO

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

DITTO Digital Twins of the Ocean

Opportunities to connect science to society

https://ditto-oceandecade.org

Co-Chairs



Fei Chai



Joanna Staneva

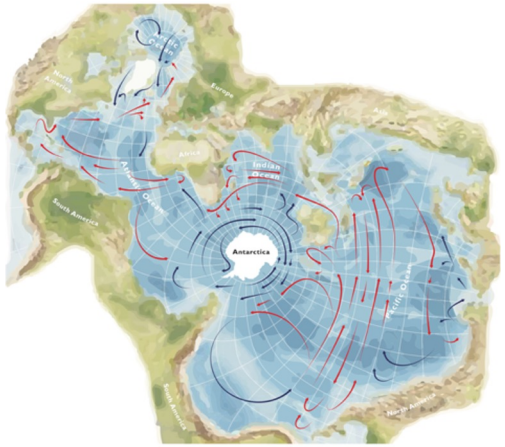
Vice-Chairs

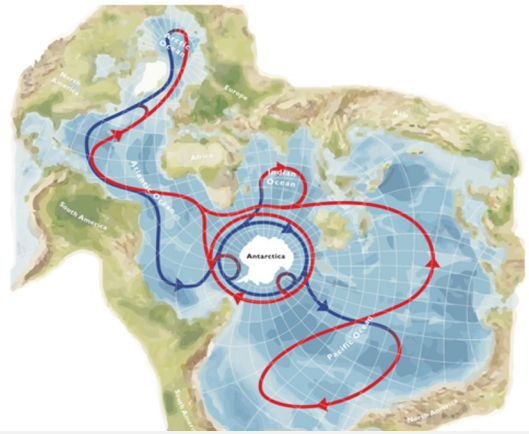


Swadhin Behera



Marina Tonani





European Commission

DITTO Digital Twins of the Ocean

G7 Future of the Seas and Ocean Initiative

One Ocean Science Congress

Marine Knowledge at the Fingertips of our Communities:
Designing Digital Twins of the Ocean

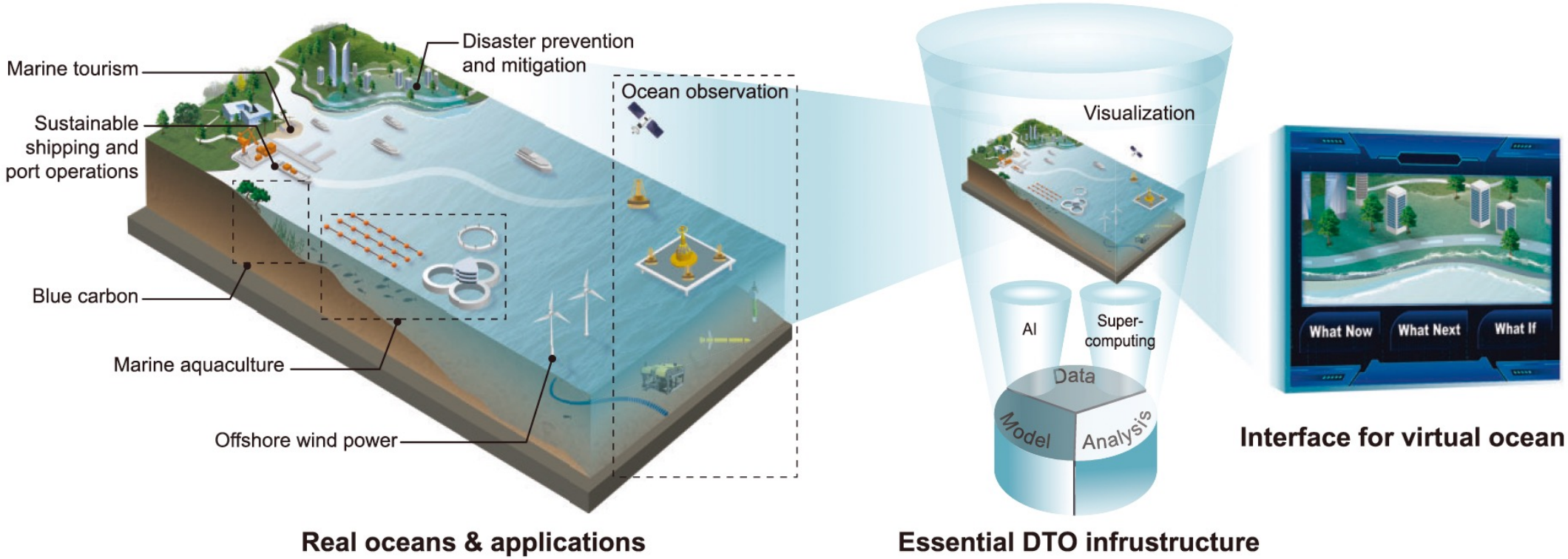
Digital twin of the ocean as a catalyst for blue economy innovation

Fei Chai[1,2,*], Qiang Deng[1,2], Minhan Dai[1,2], Xiaoyi Wang[1], Joanna Staneva[3], Swadhin K. Behera[4], Marina Tonani[5], Jian Liu[6,9], Zhaoyuan Yu[7] and Zhong Peng[8]

National Science Review (NSR), 01/2026

National Science Review
13: nwag012, 2026
https://doi.org/10.1093/nsr/nwag012
Advance access publication 20 January 2026

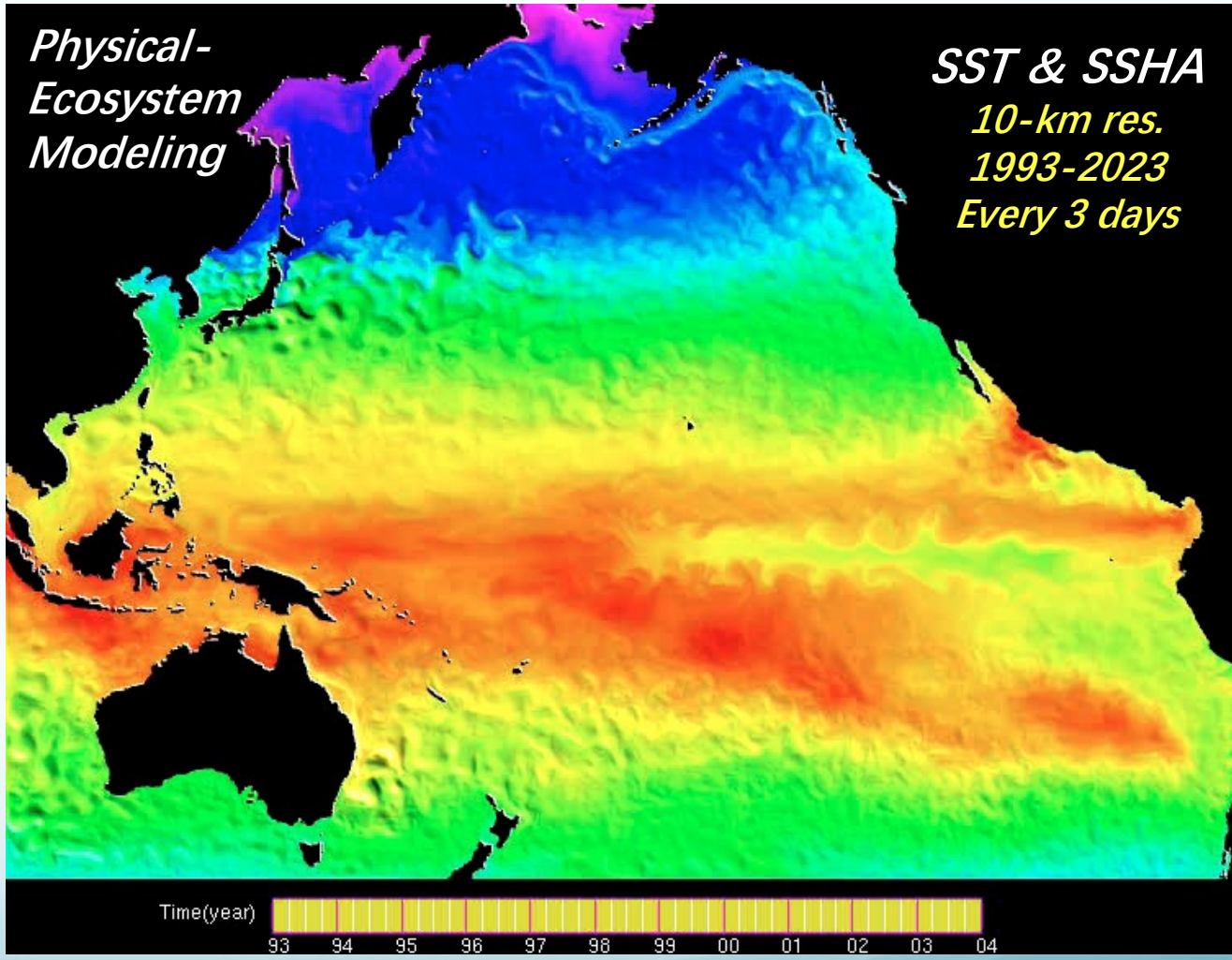
'What now', 'What next', and 'What if'



Ocean Observations



Models



Integrated Platforms

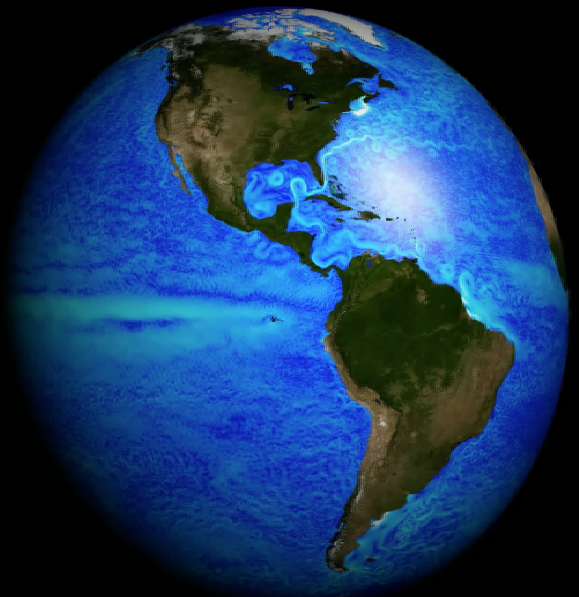
ROMS-CoSiNE

Digital Twin Ocean

- A digital framework connecting data-modeling-visualization (***real vs. virtual***)
- New tools and technologies to access and analyze ***big data*** (ML, AI, and HPC)
- It enables ***users*** and partners to create and develop different ***scenarios***
- Establishing a new globally shared and ***easy-to-use*** platforms for different communities and general public







Courtesy of Estimating Circulation and Climate of Ocean (ECCO) by JPL & MIT.

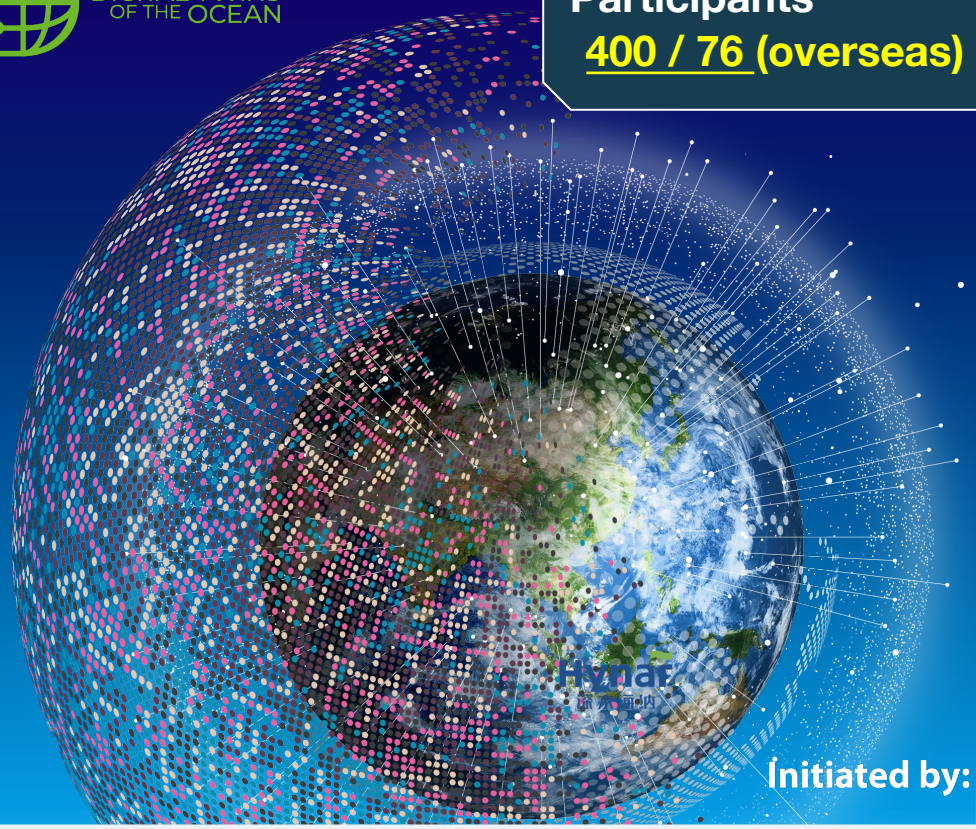
DIGITAL TWINS OF THE OCEAN

Participants
400 / 76 (overseas)

Diversity
19 nations/reg., 118 inst.

Oral presentations (keynotes)/Posters
116 (12) / 71

15 topic sessions



International Digital Twins of the Ocean Summit 2023

November 9-12, Xiamen

Co-Chairs: Fei Chai and Martin Visbeck

Initiated by: DITTO

Organisers: Fujian Ocean Innovation Center

State Key Laboratory of Marine Environmental Science (Xiamen University)

22 domestic institutions + **13** international organizations + **7** sponsors

Co-Organizers

Premier Sponsor

Tencent 腾讯 | 腾讯云

Co-Sponsors

Lenovo


We ditto the Ocean
DIGITAL TWINS OF THE OCEAN
International Digital Twins of the Ocean Summit 2023
2023 年 数 字 孪 生 海 洋 国 际 峰 会
DITTO Summit 2023

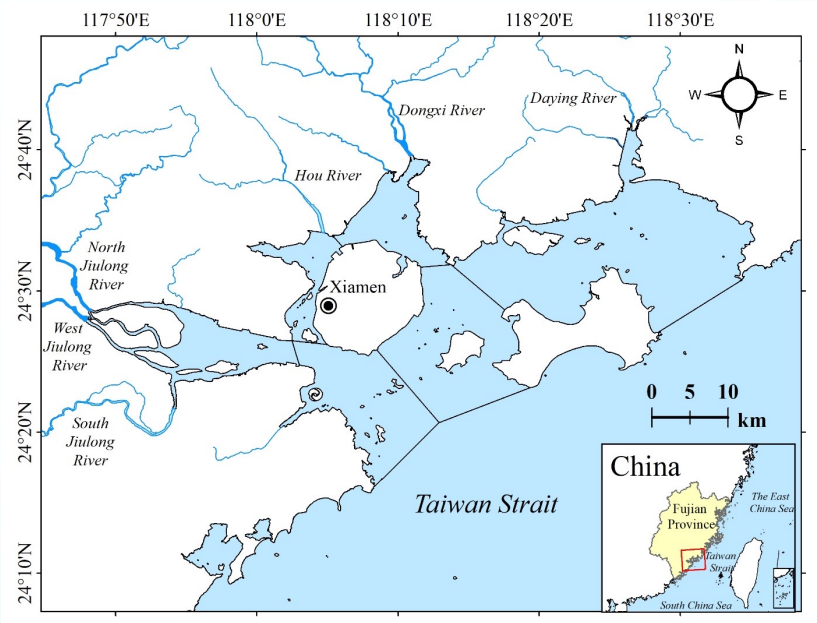

INTERNATIONAL
DIGITAL TWINS
OF THE OCEAN
SUMMIT 2026
November 11-13, 2026
DITTO @ Yokohama
Generated with Ai

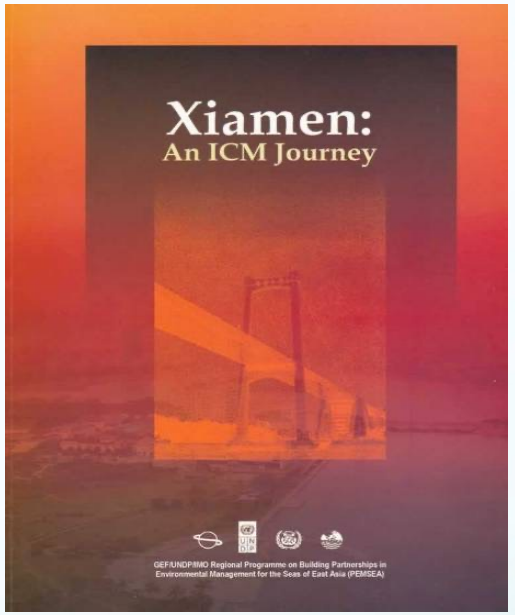
Case Study 1 : Xiamen Bay

A rapid urbanization region benefited from implementation of integrated coastal management **(ICM)**

Snapshot of Xiamen

- Population: ~5.16 million (2021)
- Land area: 1699 km^2
- Sea area: 390 km^2, Coastline: 234 km
- One of the five SEZs in China since 1980
- ICM demonstration site since early 2000
- The **7th largest** container port in China.
  The **13th largest** port in the world
- Regional Pilot City for National Marine Economic Innovation and Development.





Xiamen: An ICM Journey (Second Edition), PEMSEA, 2006

http://www.pemsea.org/publications/integrated-coastal-management



2022-04-25 星期一 09:09:09

福建台湾海峡海洋生态系统国家野外科学观测研究站
National Observation and Research Station for the Taiwan Strait Marine Ecosystem

九龙江口-厦门湾观测体系



- Multi Source Remote Sensing
- Microsatellites

sky

- Unmanned aerial vehicle (UAV) Remote Sensing

air

- Shore base station
- Video monitoring

land

- Buoy
- Ship base
- Seabed base

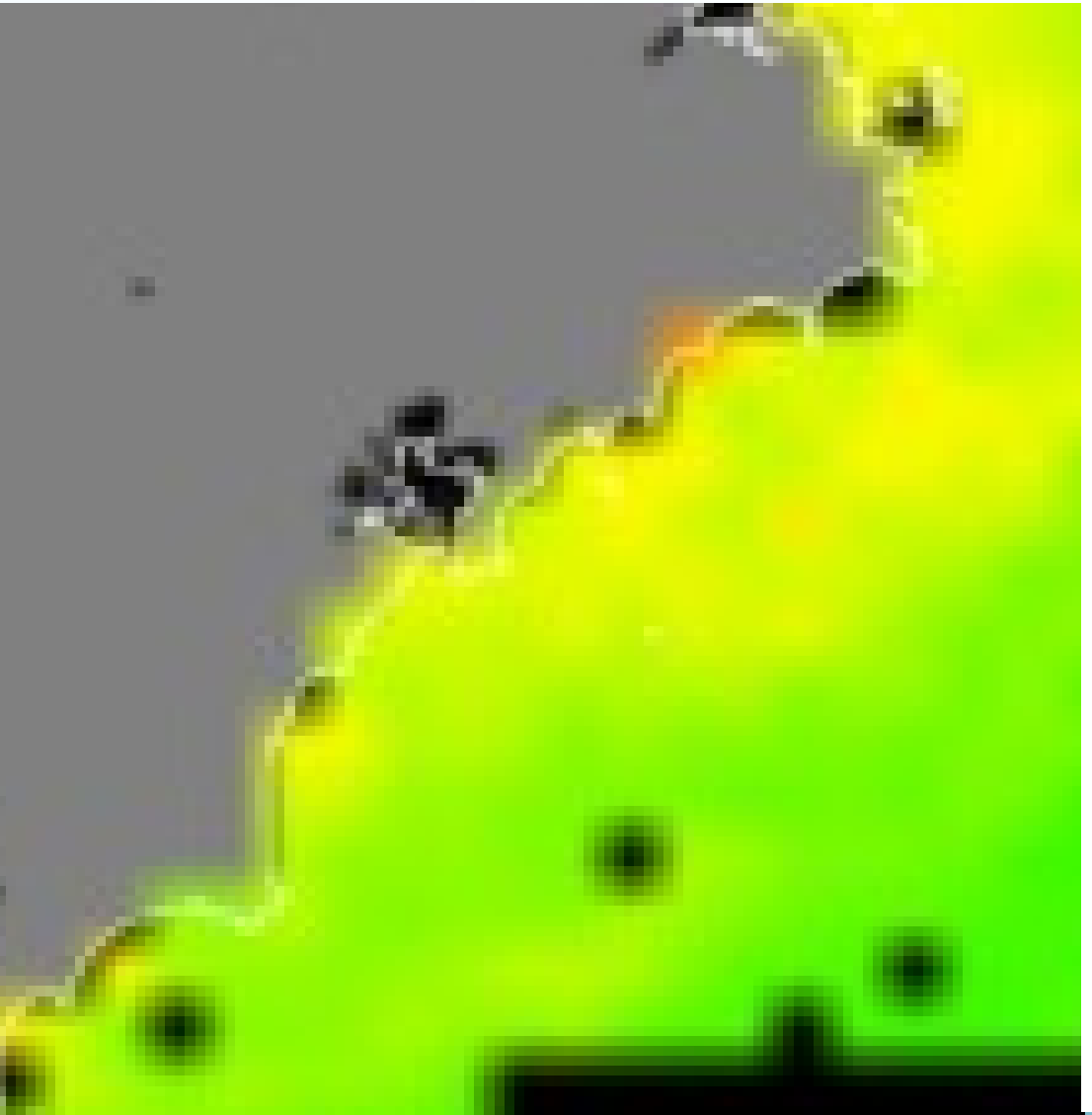
sea

返回
Return

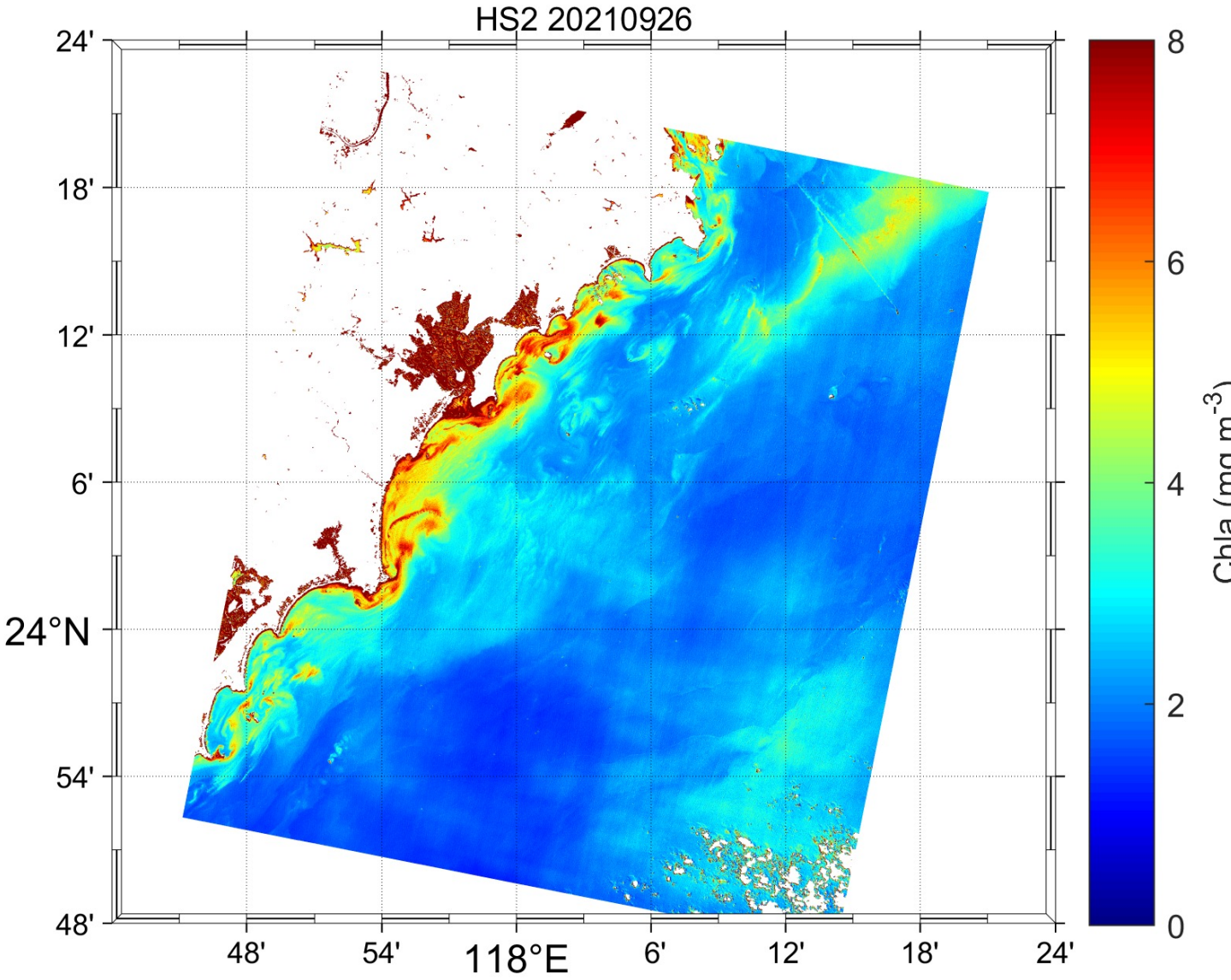
Comparison with larger satellites

Courtesy of Zhong-Ping LEE

MODIS (Chlorophyll, 500m)

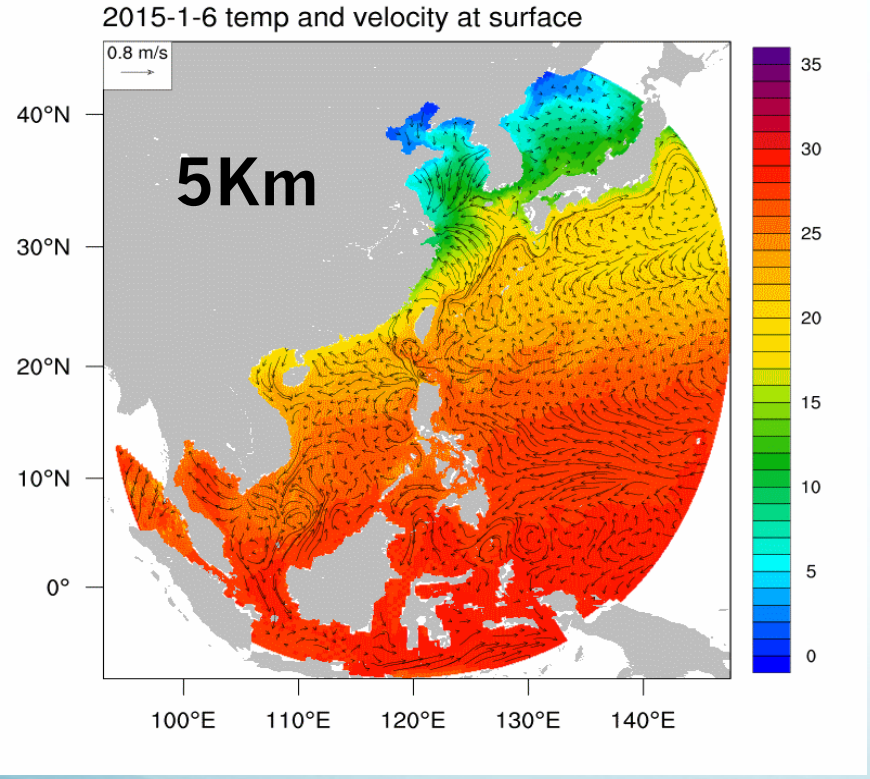


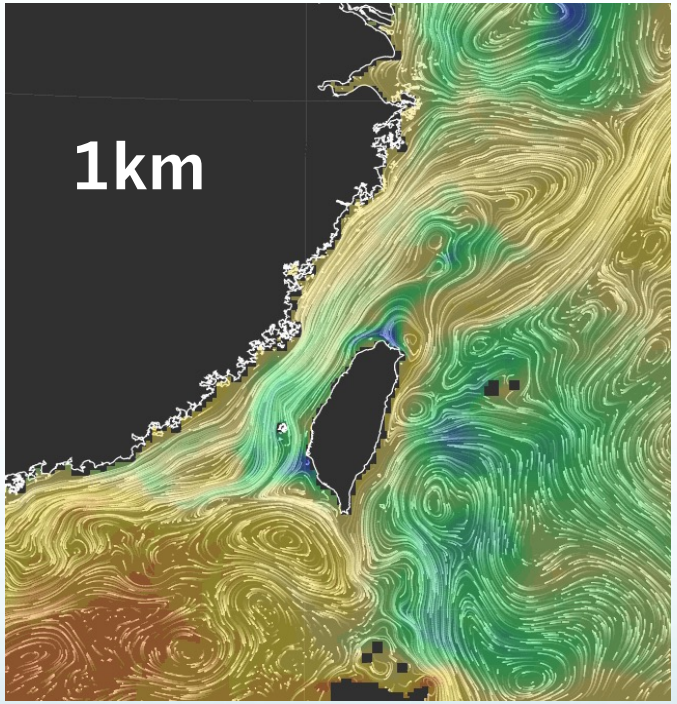
HiSEA-2 (Chlorophyll, 20m)



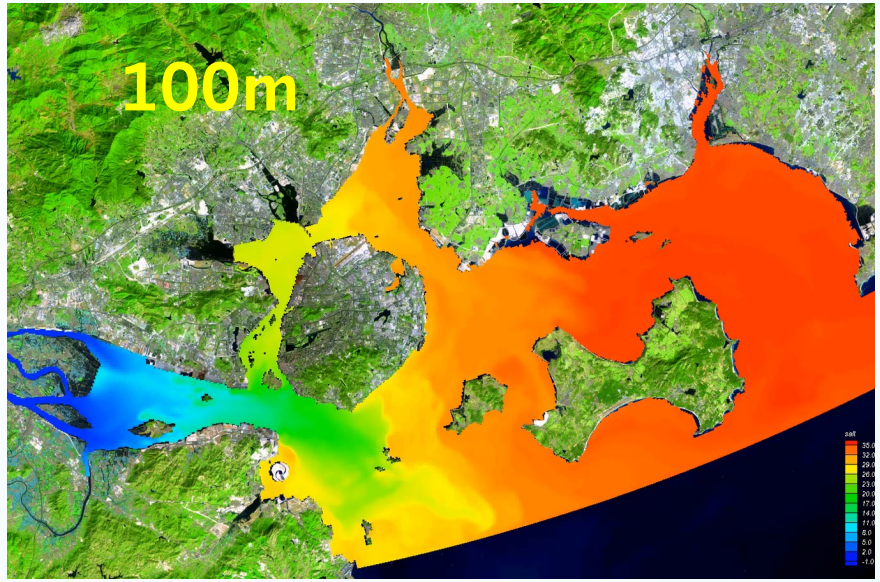
Nested models: from the Northwest Pacific and the Taiwan Strait down to Xiamen Bay

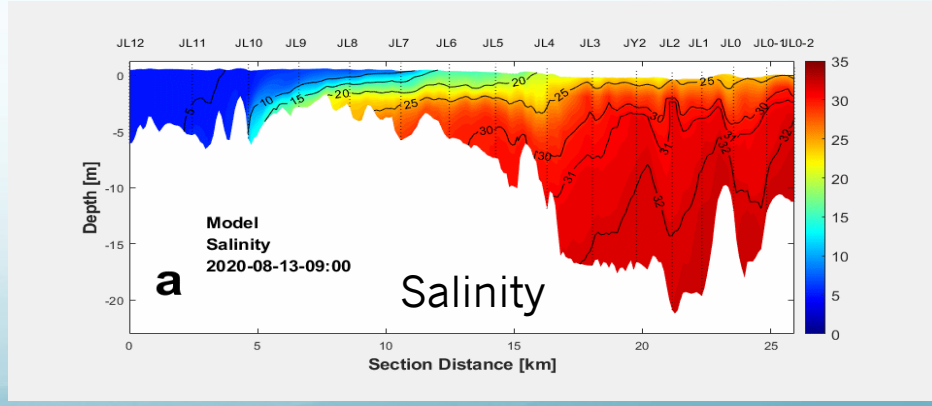
The current and SST for the northwestern Pacific Ocean and the Taiwan Strait





Xiamen Bay modeled surface salinity





Lin, Yan, Jiang & Zhang 2016 OM

DITTO for Xiamen Bay



Coastal Flooding

Xiamen

October 2024











Aquaculture industry in China and Fujian Province

- China counts about **60%** of the world aquaculture products, and Fujian is ranked 1st in China
- Annual production: **5.6** mTons (>10% of China's production), ranked **3rd** place in the world.
- Annual revenue: **10 billion RMB**; Employee: **1.7 million people**
- Marine: Freshwater = **86 : 14** (Production)
- Foreign-exchange-earnings: **6 billion USD, 26%** of the total value in China.

(Data: Chinese Fisheries Statistics Yearbook)



Large Yellow Croaker



Abalone



Nori



Oyster



Sea Cucumber

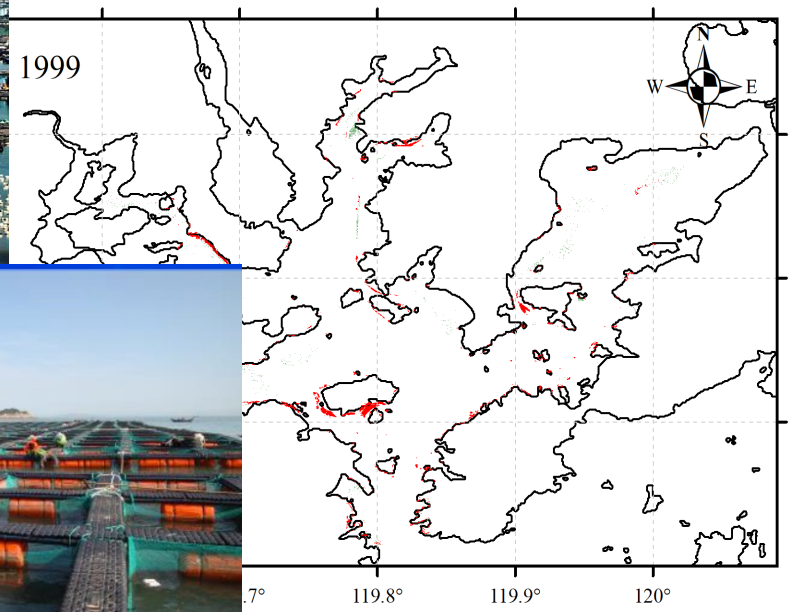
Case Study 2: San-Sha Bay



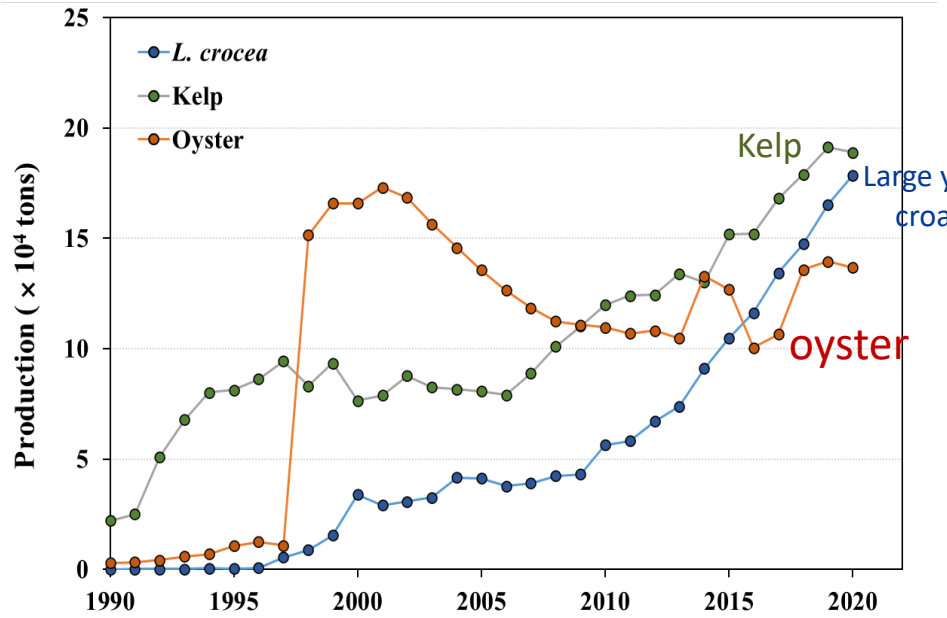




Mariculture in Sansha Bay from 1999 to 2020



Annual production of large yellow croaker, kelp and oyster



- Aquaculture activities utilize ~70% of San-Sha Bay's area
- San-Sha Bay is one of the highest density IMTA system worldwide
- Productions of L. crocea (large yellow croaker) account for 72% of total fish aquaculture production (Xie et al., 2020)

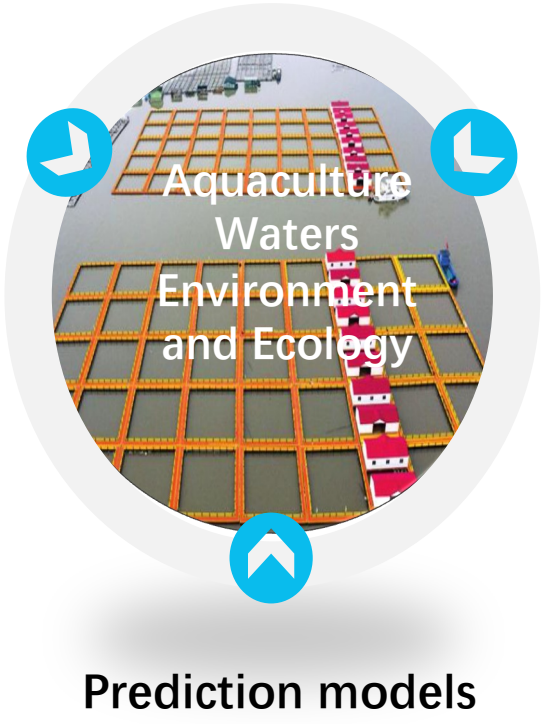
Issues:

- Over feeding & eutrophication
- Overuse of ocean space
- Low resiliency and not sustainable

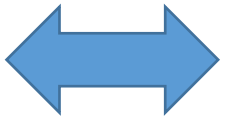
Development of Digital Twin System

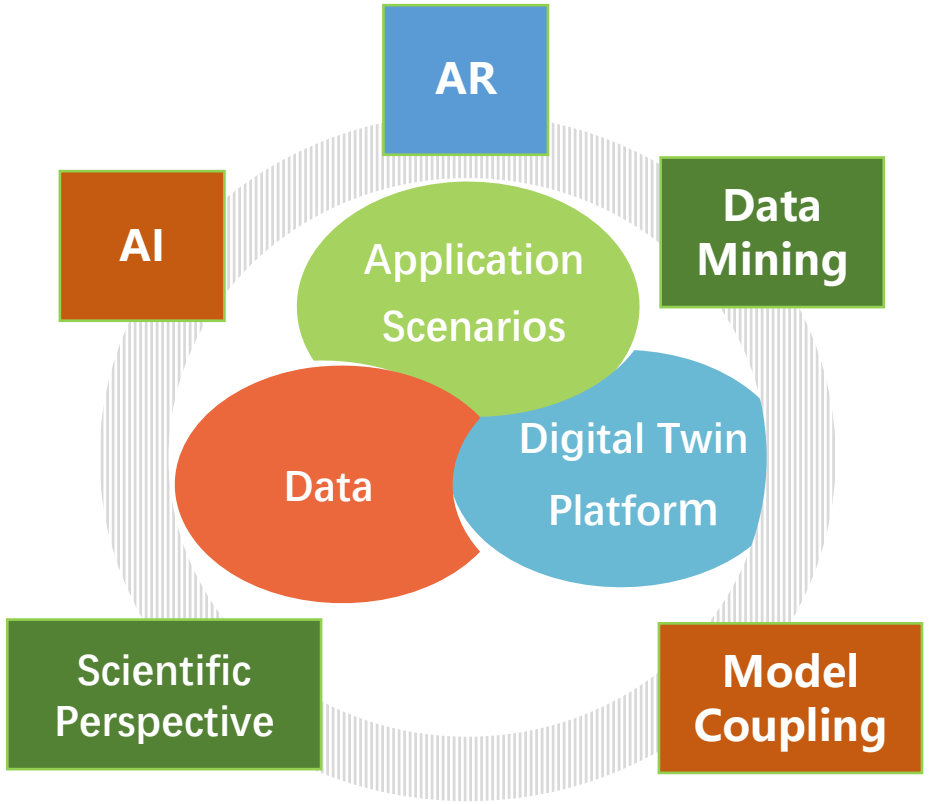
- Establish data platform, gathering bay-wide multi-source data
- Conduct an end-to-end system from monitoring, modeling to early warning system of extreme weather events (salinity, temperature), red tides and low oxygen
- A Digital Twin that supports day-to-day aquaculture decisions

real-time monitoring (data)



Physical-ecosystem simulations





Design of San-Sha Bay Digital Twin System

Multidimensional Monitoring

Model Forecast

Intelligent Early Warning

Simulation and Contingency Planning

Marine Ranching

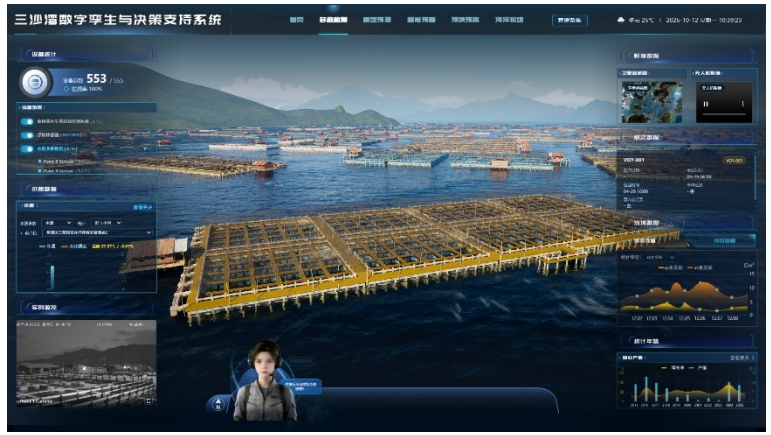
AI Agent



San-Sha Bay Digital Twin System

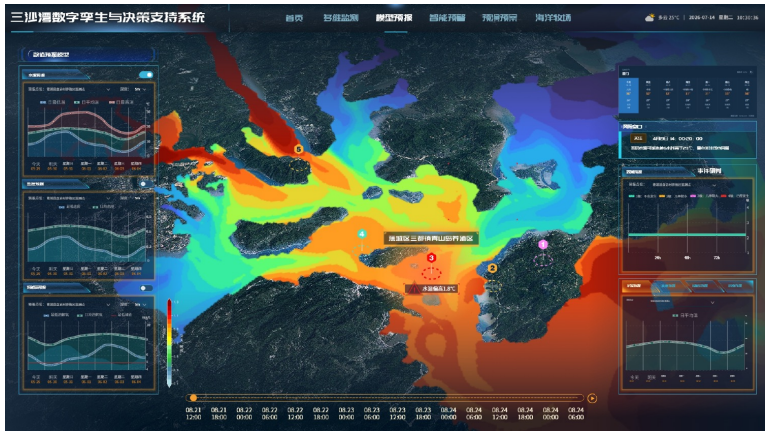
Multi-dimensional Monitoring

What now?



Model Forecasts

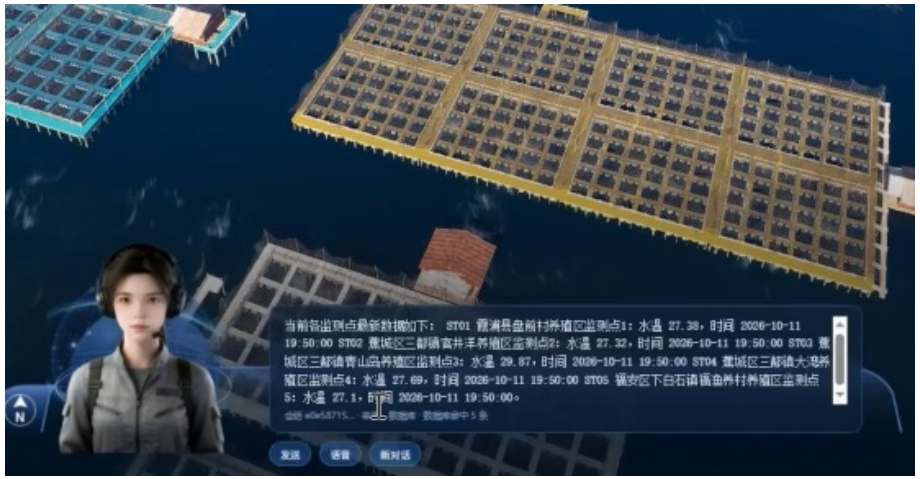
What next?



Simulations and Spatial Planning

What if?





AI Agent based on Expert Knowledge Base

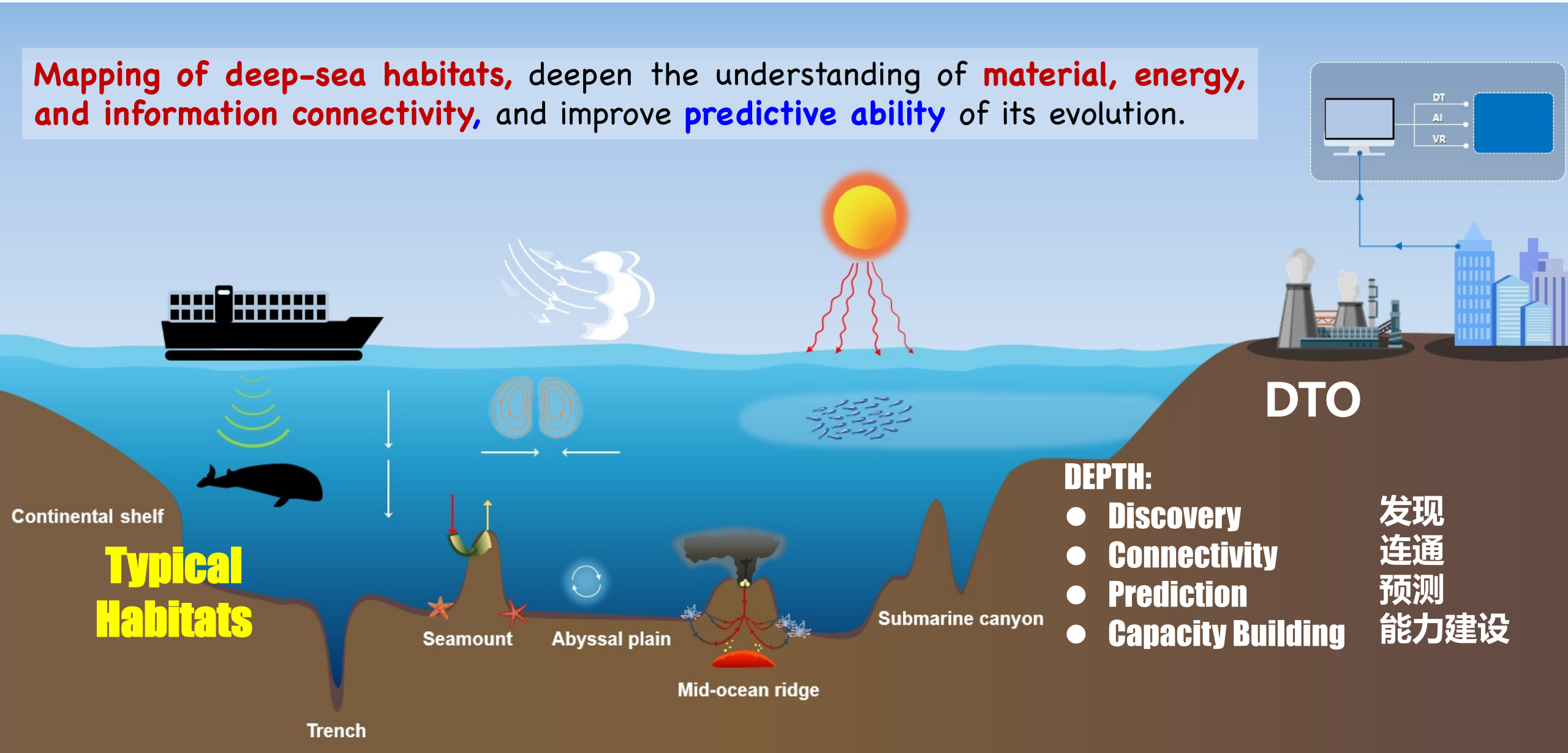


Sharp Island (Hong Kong) Digital Twin



Digital DEPTH -- Digital DeEP-sea Typical Habitats (led by Jiabiao LI)

Mapping of deep-sea habitats, deepen the understanding of **material, energy, and information connectivity,** and improve **predictive ability** of its evolution.



DEPTH:

- **Discovery** 发现
- **Connectivity** 连通
- **Prediction** 预测
- **Capacity Building** 能力建设

Intelligent Seamount Digital Twin Systems

UN Ocean Decade endorsed programme

Digital DEPTH

Digital DeEP-sea Typical Habitats

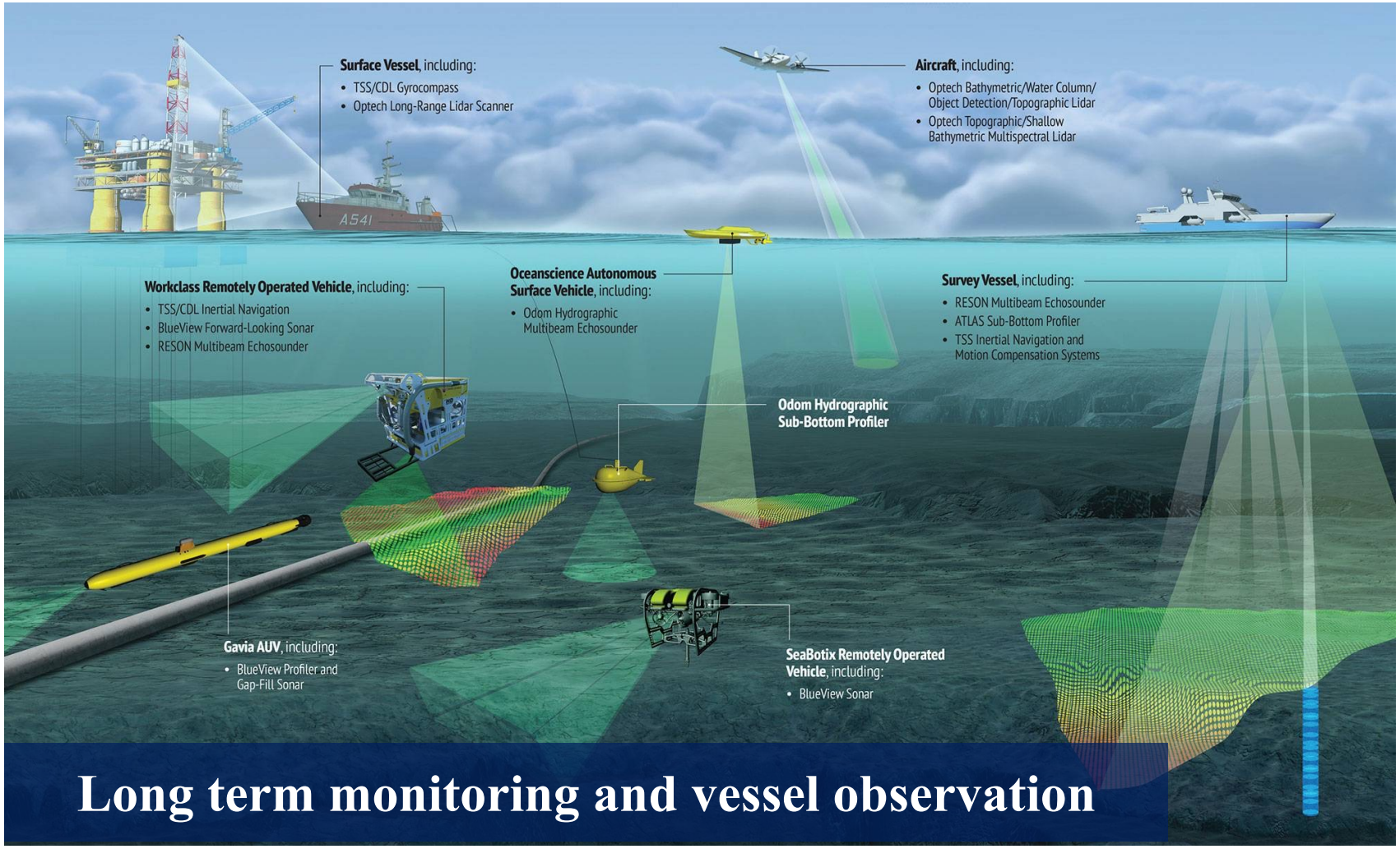
GAO Yan, WANG Yuntao, SHI Junhui, XU Xuewei, CHAI Fei
Chief scientist: LI Jiabiao

China Deep Ocean Affairs Administration
Second Institute of Oceanography, MNR
Zhijiang Lab, Xiamen University, National Deep Sea Center

之江实验室
ZHEJIANG LAB

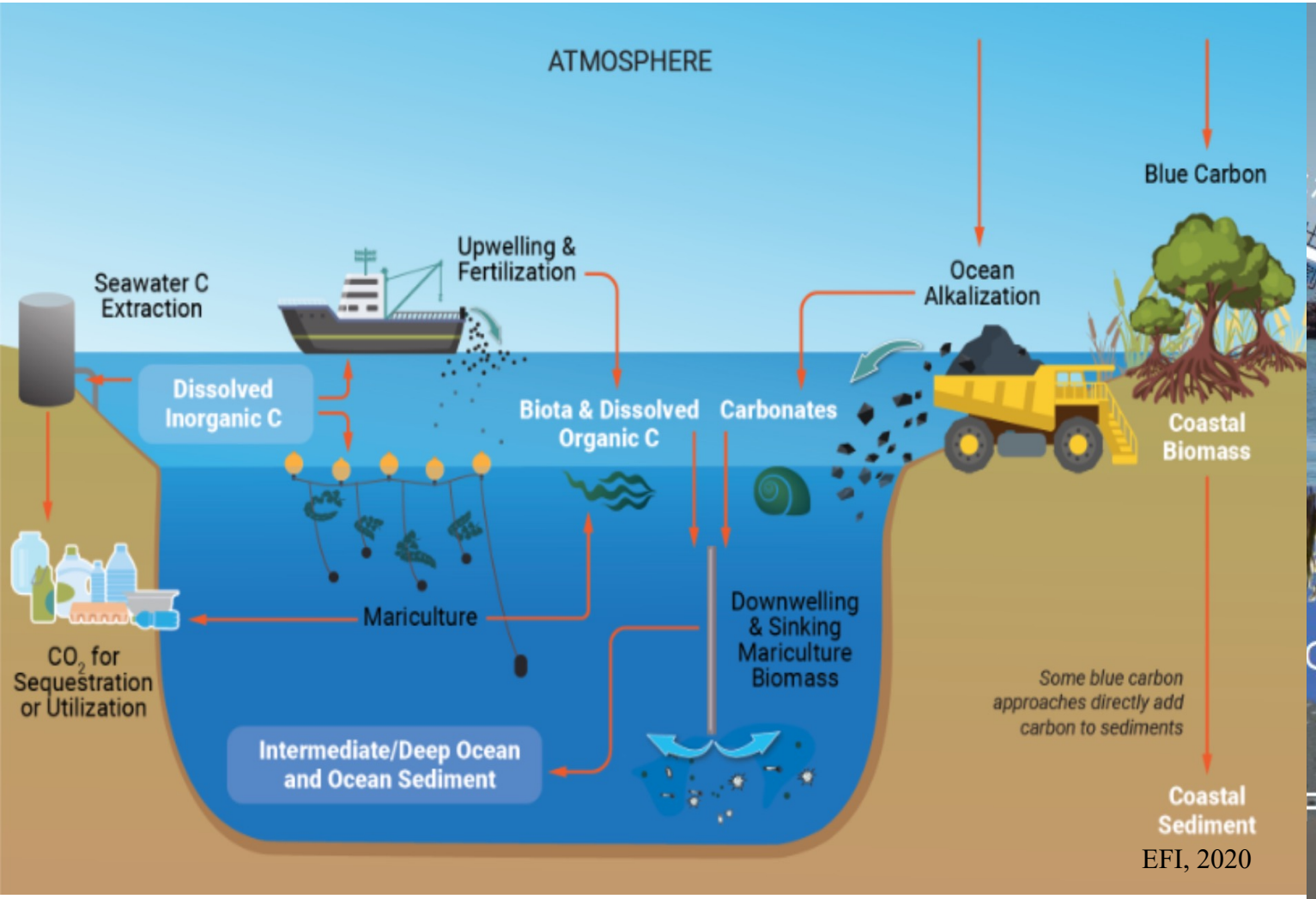
中国大洋事务管理局
China Deep Ocean Affairs Administration

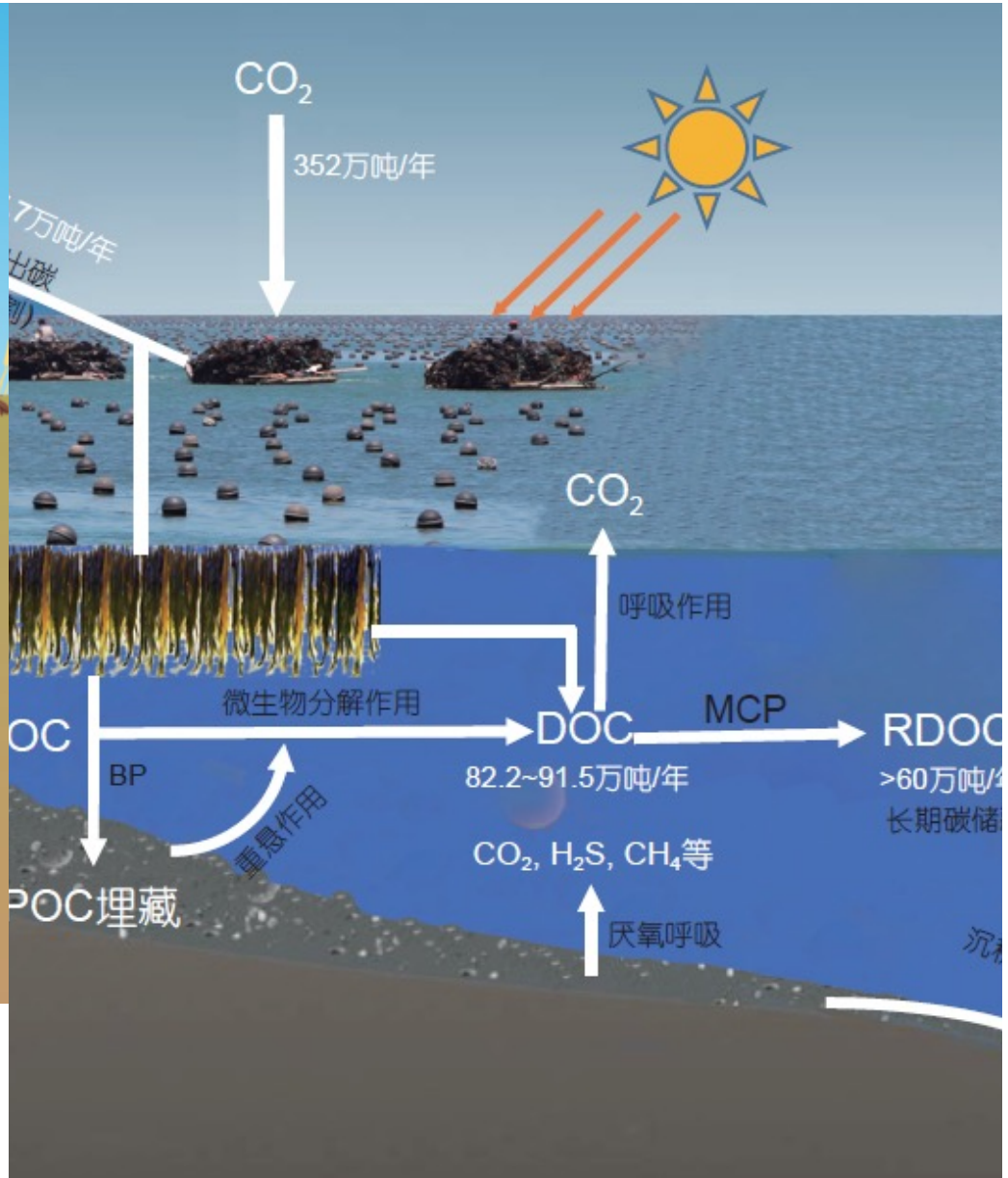
Efforts to Understand, Protect, and Develop Deep Sea





Ocean-based Carbon Dioxide Removal (CDR) Methods





Using observations and physical-biogeochemical models and DITTO to test different CDR methods.

Some final thoughts on

Observations-Modeling-Digital Twin Ocean

- **Digital Twin Ocean** connecting data-modeling-visualization (***real vs. virtual***)
- Multiple sources of information (***data and model outputs***), need to know where and how to access, and develop standards and best practices
- **DITTO** can incorporate the latest **ML** and **AI** in a common framework
- Co-design for **Digital Twin Ocean** with multiple ***users*** and ***objectives***
- Working closely with global communities to establish ***regional*** and ***targeted*** and ***easy-to-use*** digital twin ocean for simulating and forecasting ocean conditions
- Connect different stakeholders and partners to access digital twin ocean information and ***test different scenarios*** for natural, social & economic impact
- Capacity building and training to use and refine ***regional digital twin ocean*** and develop a common approach for different ***users*** and ***objectives***

One Planet, One Ocean
One Bay at a Time



谢谢!

Thank you!

Prof. Fei CHAI
Xiamen University

with a digital twin!