中国地质大学
CHINA UNIVERSITY OF GEOSCIENCES

第六届WMO-IOC亚太区域海洋仪器检测技术研讨会
Sixth Marine Instrumentation Workshop for Asia-Pacific Region

Marine phytoplankton carbon calculation and its carbon sink

SUN, Jun

E-mail: phytoplankton@163.com

China University of Geosciences

Virtual

16 December 2021

Content

1 Carbon peak & neutrality

2 Pathway for marine neutrality

- Biological pump
- Blue carbon
- Fishery carbon sink
- Ecosystem carbon sink
- Microbial carbon sink
- Geological carbon sequestration
- Land-sea carbon sink

3 Phytoplankton carbon measurement

- Carbon measurement
- Carbon sink measurement

Content

- **1 Carbon peak & neutrality**
- **2 Pathway for marine neutrality**
  - Biological pump
  - Blue carbon
  - Fishery carbon sink
  - Ecosystem carbon sink
  - Microbial carbon sink
  - Geological carbon sequestration
  - Land-sea carbon sink
- **3 Phytoplankton carbon measurement**
  - Carbon measurement
  - Carbon sink measurement

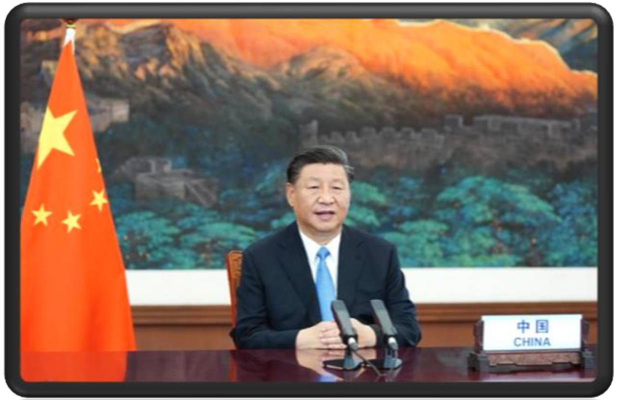
1 1.5 °C temperature increase & Carbon peak & Carbon neutrality

- The IPCC report(2018):limit global warming to 1.5°C， from 1.5°C-2 °C , will lead to climate system unstability and unreversible changes of earth system stratums
- If limit to 1.5°C:global water scarcity population will reduce by 50%, people suffered from extreme weather will reduce 64 million, coral reef decrease will slow down (70%-90%)
- Climate change impacts global economy and social sustainable development

1 Carbon reduction: carbon peak & carbon neutrality

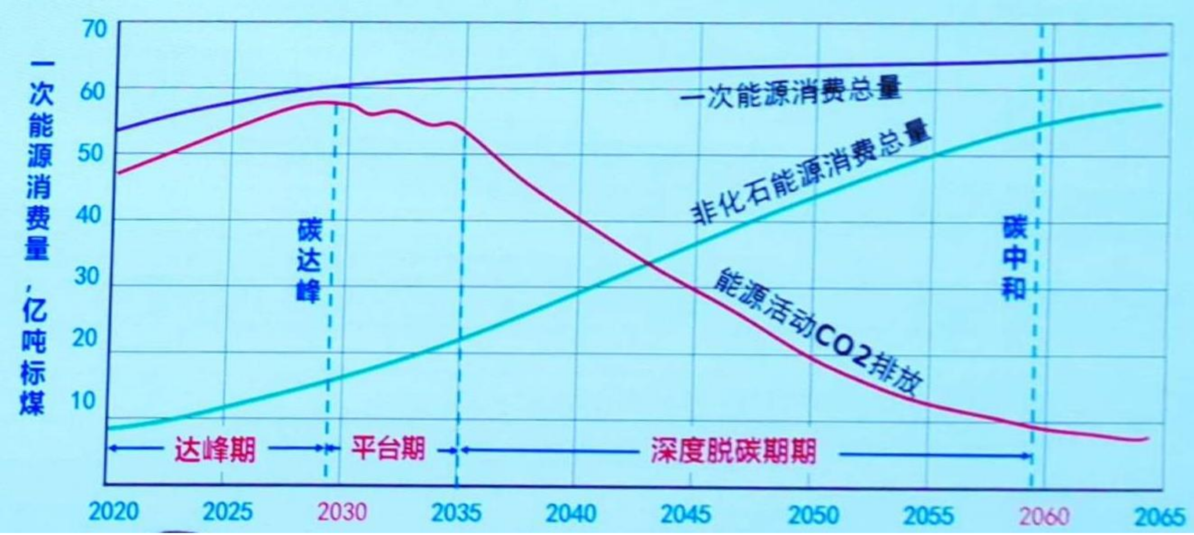
● Statement by H.E. Xi Jinping President at the General Debate of the 75th Session of the United Nations General Assembly, 22 September 2020: **China will scale up its Intended Nationally Determined Contributions by adopting more vigorous policies and measures. We aim to have CO_2 emissions peak before 2030 and achieve carbon neutrality before 2060.**

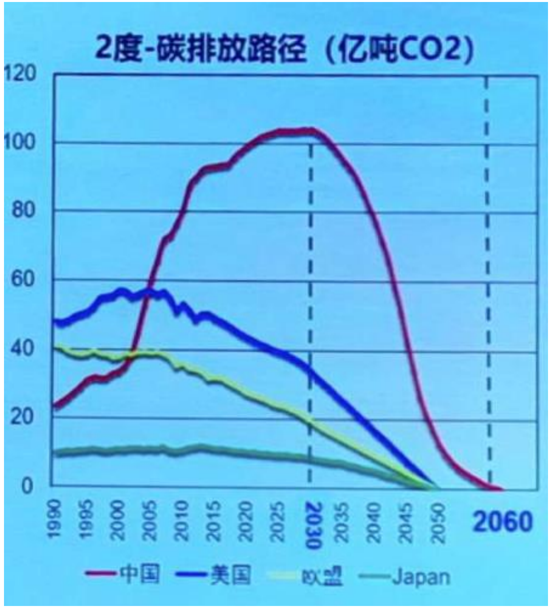
● Statement by H.E. Xi Jinping President at the Climate Ambition Summit,12 December 2020：**① China's CO_2 emissions per unit GDP will decrease 65%;② The share of non-fossil energy in primary energy consumption will reach 25%;③ Forest stock will increase by 6 billion cubic meters compared with 2005;④ The total installed capacity of wind and solar power will reach more than 1.2 billion dry watts**



●…… Tackle climate change is the essential requirement of China's sustainable development

1 China's carbon peak and carbon neutrality potential





Developing countries have 50-70 years from carbon peak to carbon neutrality, **while China only has 30 years**

"carbon peak", CO_2 emissions reach peak at some time point, then "carbon neutrality", reduce gradually until offset of anthropogenic output and removal (natural+artificial)

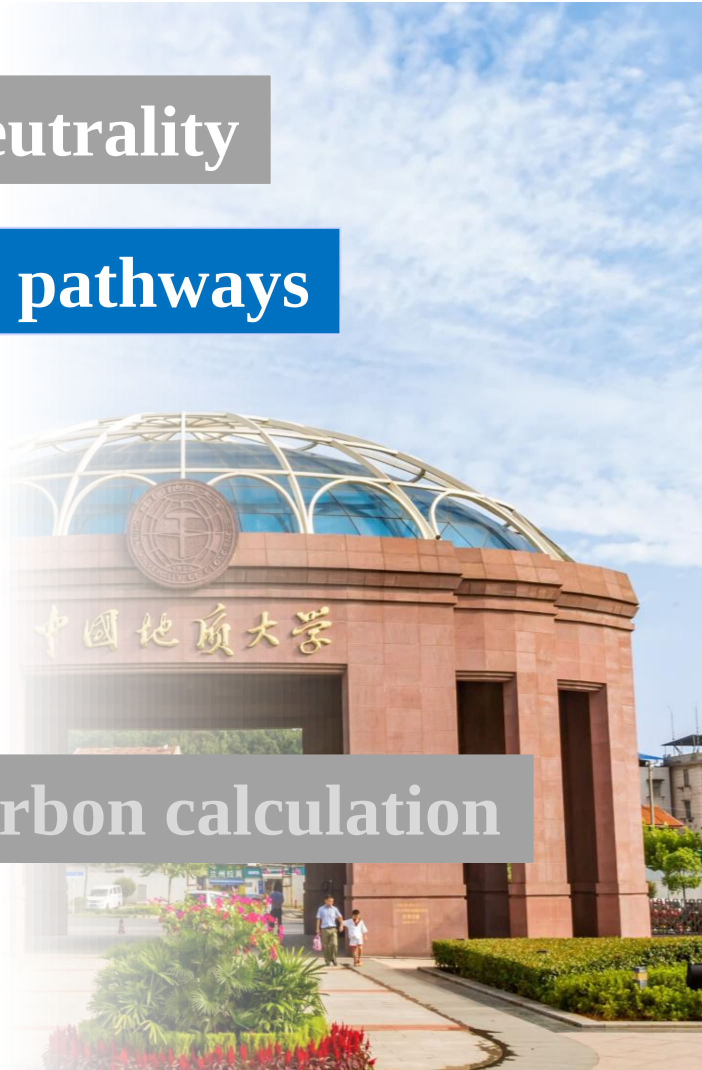
1 carbon neutrality: task of technology——pathway

Carbon emissions reduction & increasing carbon sinks are two approaches of carbon neutrality。

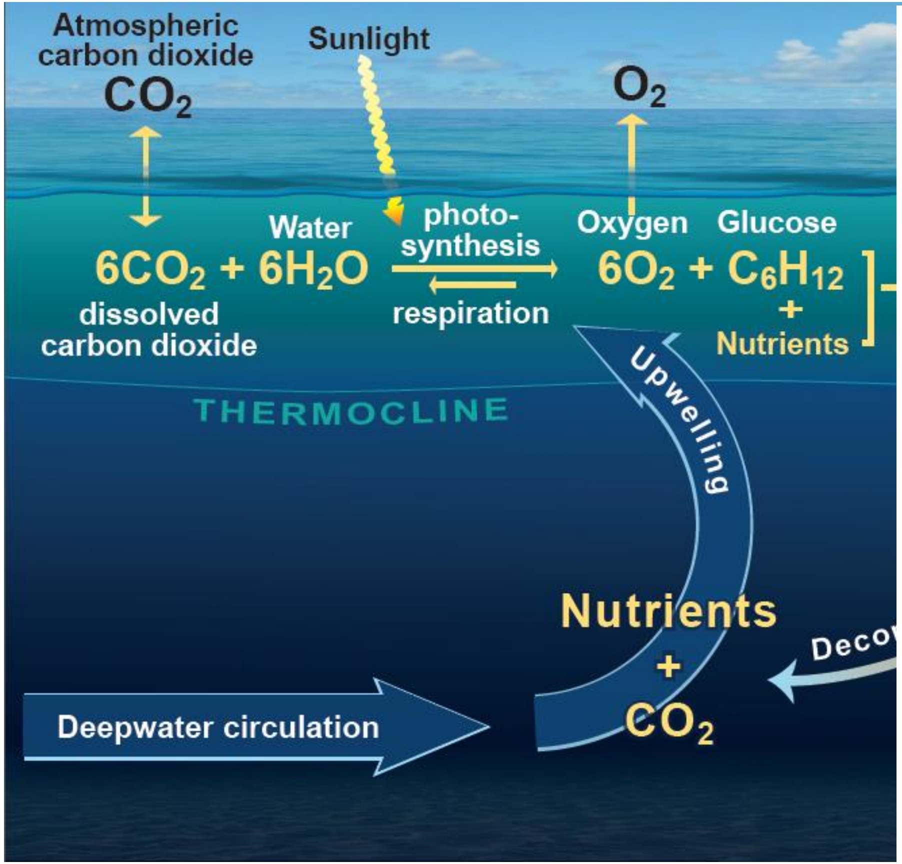
- Emissions reduction pathway
- Measures and Policies
- Terrene: pattern of carbon sink, time scale, evolutionary trend
- Oceans: pattern of carbon sink, time scale, evolutionary trend
- Climate system: feedback mechanisms
- Carbon trap&sequestration: acmechanisms, fixation effectiveness, carbon sink potential, and technical risk
- management: Economic transformation in science and policy research, Carbon neutrality path, national climate governance system and international climate cooperation

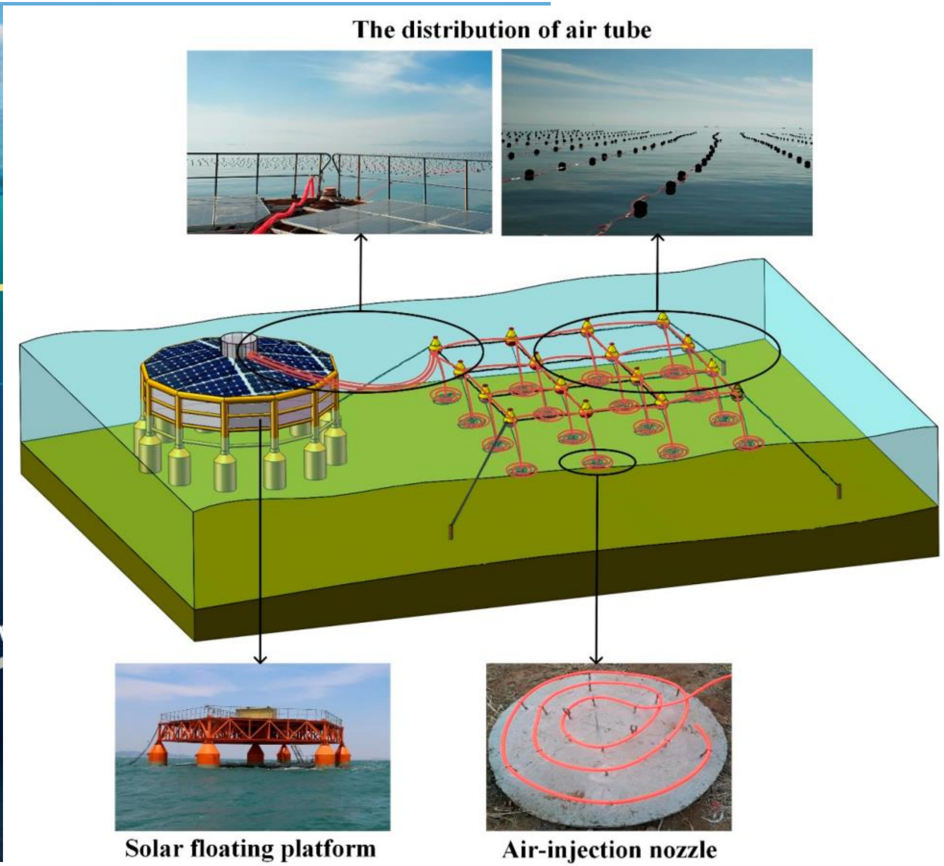
Contents

- **1 Carbon peak & carbon neutrality**
- **2 Marine carbon neutrality pathways**
  - Biological pump
  - Blue carbon
  - Fishery carbon sink
  - Ecosystem carbon sink
  - Microbial carbon sink
  - Geological carbon sequestration
  - Land-sea carbon sink
- **3 Marine phytoplankton carbon calculation**
  - Carbon storage calculation
  - Carbon sink calculation

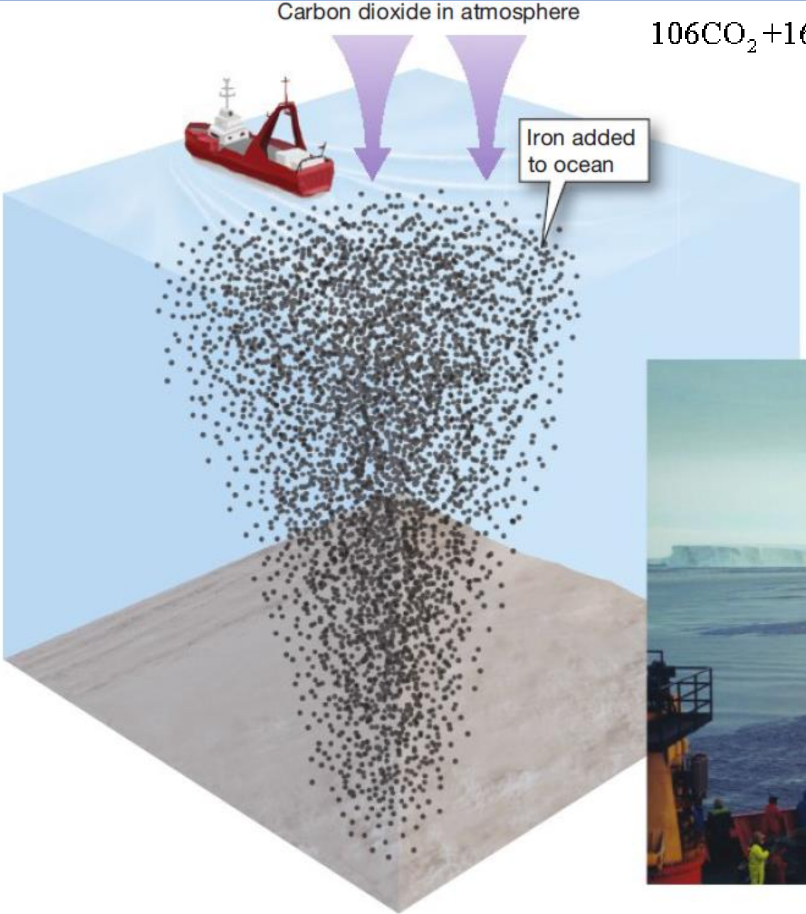


2.1 Marine biological pump for increase carbon sink——artificial upwelling





2.2 Marine biological pump for increase carbon sink——iron fertilization experiment



$$106CO_2 + 16HNO_3 + H_3PO_4 + 122H_2O \underset{\text{Respiration}}{\overset{\text{Photosynthesis}}{\rightleftharpoons}} (CH_2O)_{106}(NH_3)_{16}H_3PO_4 + 138O_2$$

The iron hypothesis: iron transported to the oceans in aerosols could fertilize biological productivity. Carbon in the form of organic carbon or fecal pellets will sink to seafloor, and finally be removed from atmosphere.

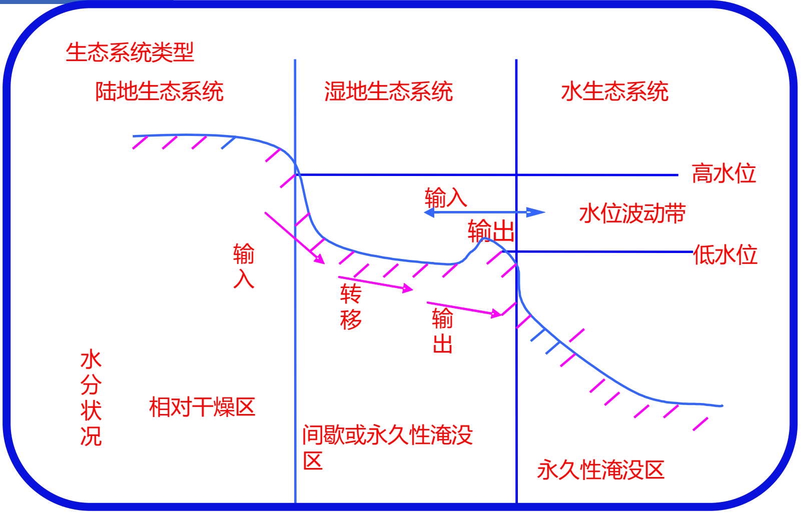
2.2 Marine carbon sink pathways——coastal wetland

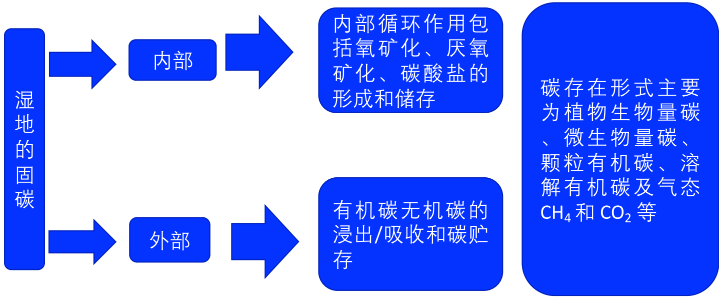
Mangrove forest

Salt marsh wetland

Kelp beds

Seagrass beds

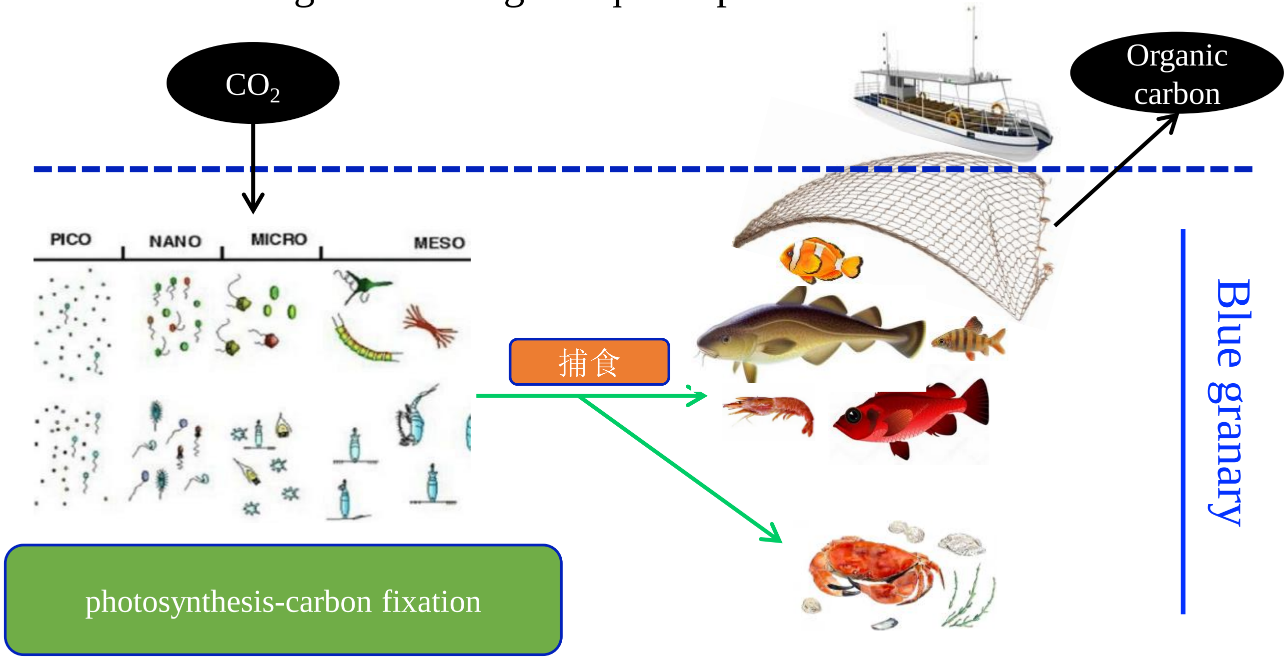


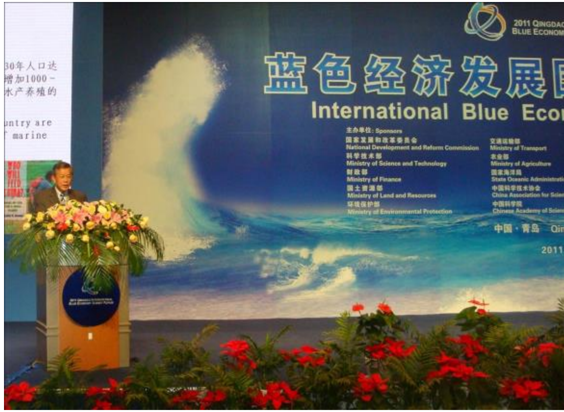


Coastal wetland: estuary, shallow sea, beach, saltmarsh, tidal plat, tidal creek, peat bog, sandbank, shoal, lagoon, mangrove, coral reef, seagrass beds, bay, seawall, island. The annual fixed carbon offsets about a third of the carbon released.

2.3 Marine carbon sink pathways——marine fishery carbon sink

"Fishery carbon sink" promote the uptake of CO2 by aquatic organisms from water through fisheries and the removal of this carbon from water through harvesting of aquatic products.





2.3 Marine carbon sink pathways——
marine fishery carbon sink

"Fishery carbon sink" is the major concern of "blue granary" strategy and the theoretical basis under the framework of ecological sustainability.

Mariculture removes an average of 2.3 million tons of carbon from the water each year;

By 2030, China's mariculture output will reach 25 million tons;

China's mariculture output is expected to reach 35 million tons by 2050;

The total carbon sink of mariculture can reach 4 million tons of carbon 。

Fishery carbon sink

Ensure the sustainable development of fisheries

Measures

Breed varieties with high C- fixation rate

Combination of breeding varieties scientifically

Improve breeding technology and methods

Ensure the national strategic needs of " blue granaries"

Measures

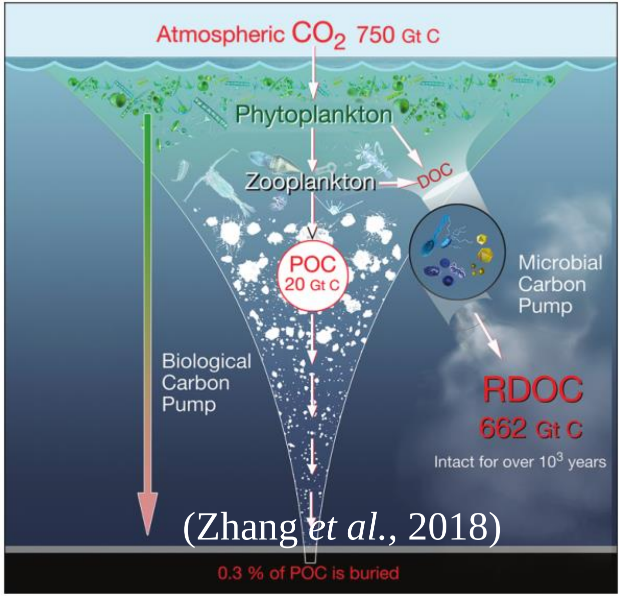
Ocean ranch planning and construction （key）

Establish an international blue carbon trading system

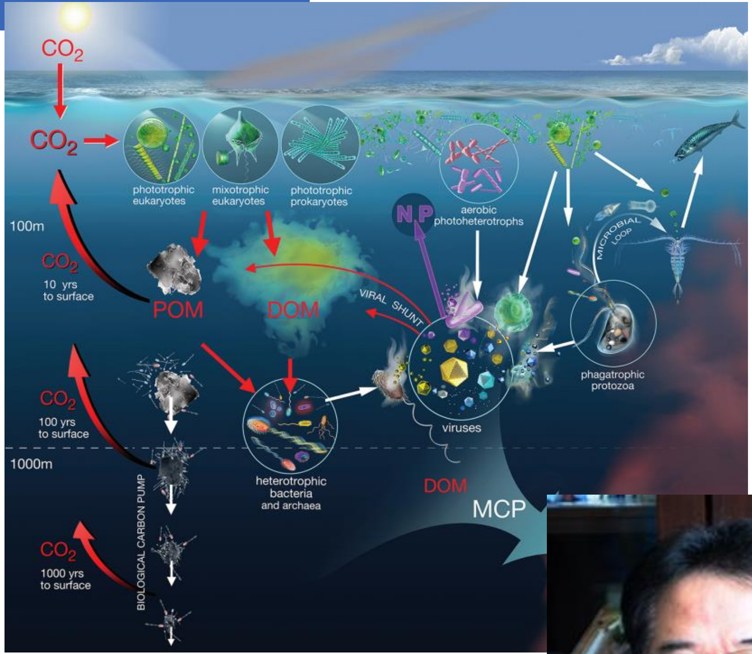
expand cooperation in aquaculture among countries along the Belt

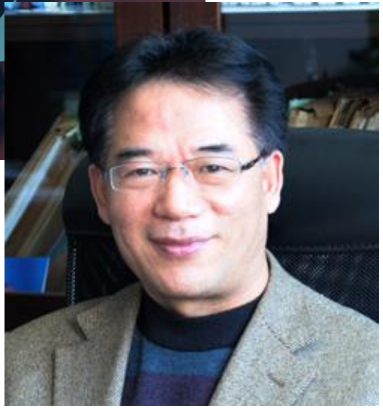
2.4 Marine carbon sink pathway——microbial carbon pump

Biological Carbon Pump (MPC): a process whereby CO_2, which accumulates in deep waters until it is eventually in the upper ocean is fixed by primary producers and transported to the deep ocean as sinking biogenic particles or as DOM. However, a proportion of the fixed carbon is not mineralized but is instead stored for millennia as Recalcitrant Dissolved Organic Carbon (RDOC).



(Zhang *et al.*, 2018)



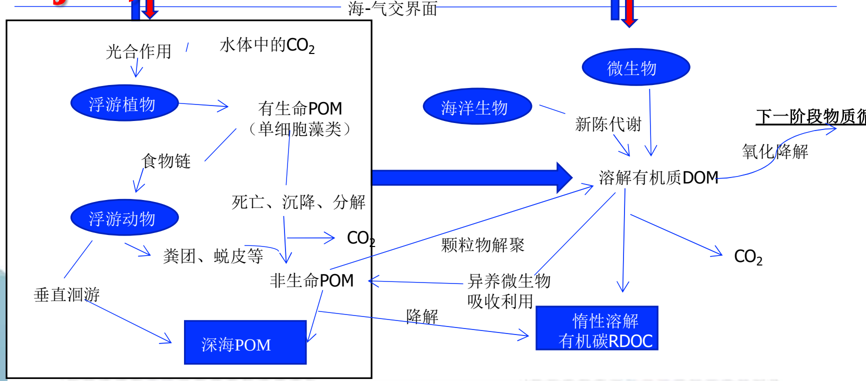


MCP: a framework to explicitly assimilate environmental, trophic, physiological, molecular and genomic data that are relevant to the in situ microbial activities which regulate RDOM production and dynamics.

2.5 Marine carbon sink pathway——negative emissions& increasing carbon sink of ecosystems

- **Artificial ecosystem restoration project, Corel reef etc.**

Corel reef ecosystem: mode for increasing carbon sink



参考（生态环境研究所 深港环境科学研究院）

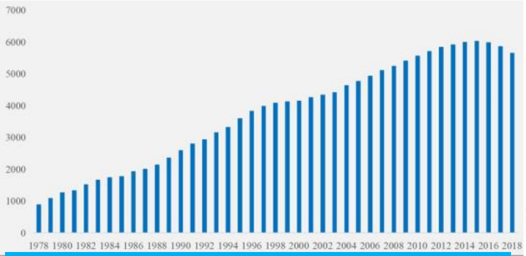
2.6 Marine carbon sink pathway——marine geological carbon sequestration

Sensor-laden CO_2 sequestration setup

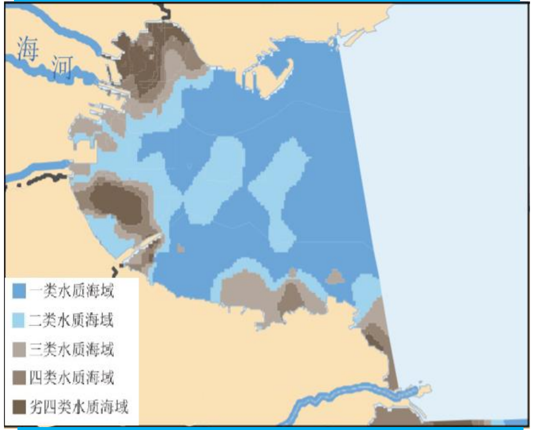
- To achieve global CO_2 negative emissions
- A climate engineering technique used to achieve long-term CO_2 sequestration by feeding CO_2 emissions into the seabed or Marine formations via pipelines and shafts (Brewer et al. 2004)。
- Carbon storage-related geological techniques
  - **Simple CO_2 sequestration technology in seabed formation**
  - **Dynamic storage technology(CO_2 --EOR)**
- Japan, The United Kingdom, the United States, Vietnam, Malaysia, Brazil and other countries have carried out such engineering technology research.
- Many sea areas in China meet the requirements of Marine geological carbon sequestration (Jiao et al. 2021)。

2.7 Marine carbon sink pathway——
land & ocean coordinating carbon neutrality

The land nutrient salt will be converted from waste to treasure, instead of pollutant to increase the sink



1978-2018年全国化肥使用量



2018年渤海湾水质分布示意图

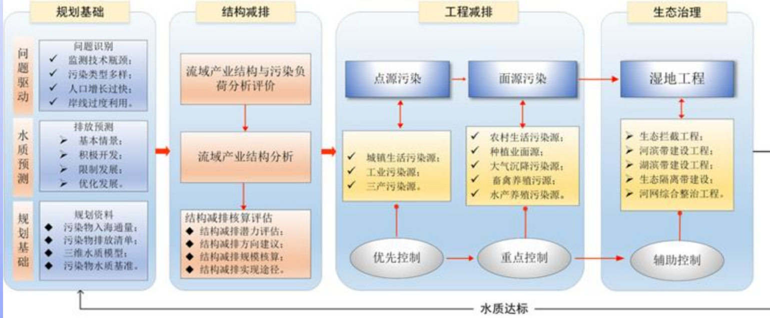
Optimize the allocation of environment capacity：

- ◆ 允许入海量——海域环境功能区环境容量——海洋规划；
- ◆ 允许入河量——河流环境功能区环境容量——流域规划——允许纳污量分配；
- ◆ 允许排放量——区域环境容量——（行政区）排放总量分配方案；

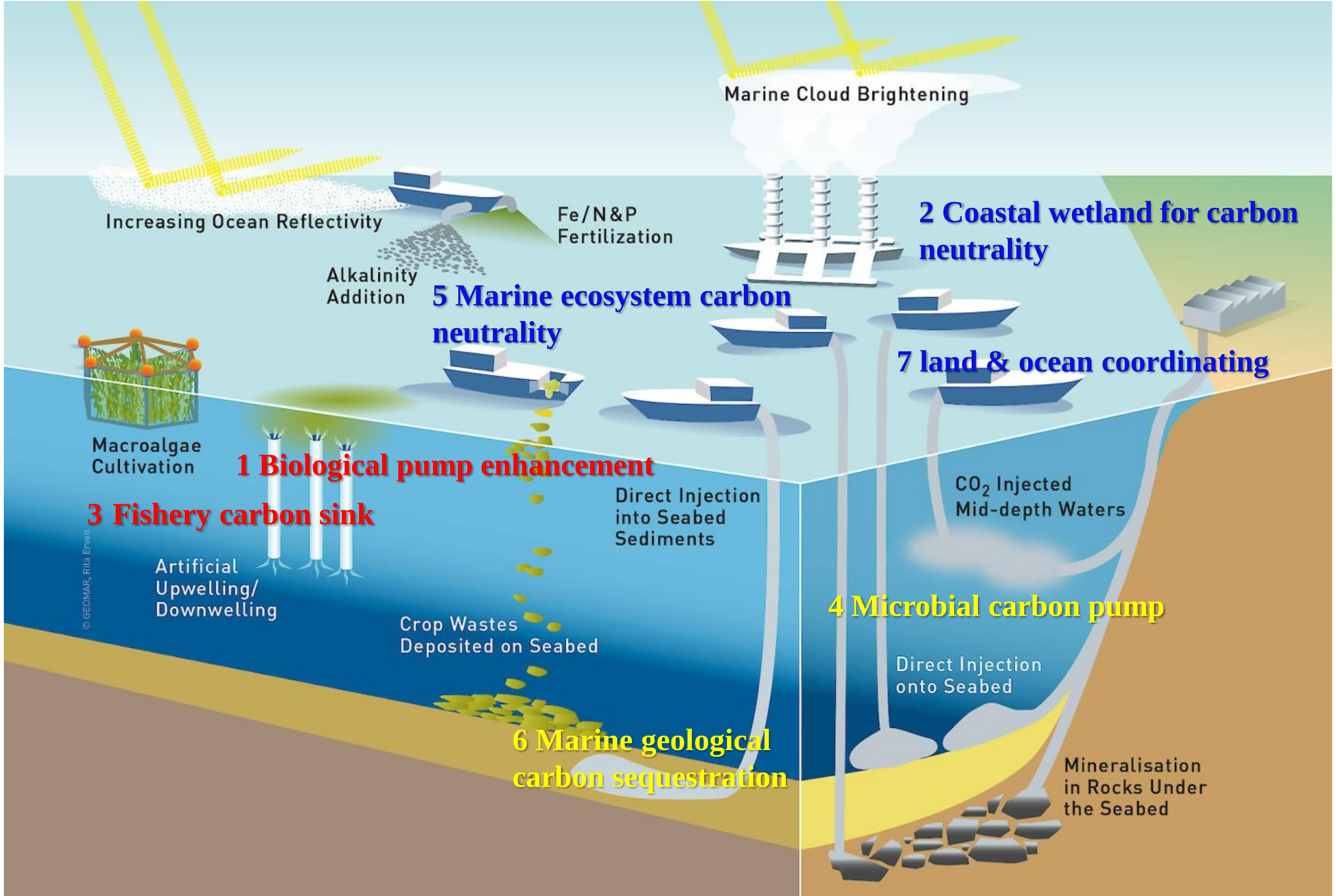
CO_2 negative emissions scheme：

陆海统筹管理分区的污染调控机制

- ■ Pollution abatement allocation model construction in the Bohai Bay
- ✓ by stages：recent、mid-term、future
- ✓ regionalize：negative emissions depend on regions；
- ✓ interval plan: deal with uncertainties in the system
- ✓ scenario analysis： Design comparisons between different situations



2.8 Marine carbon sink pathways



1 Biological pump enhancement

2 Coastal & wetland carbon neutrality

3 Fishery carbon sink

4 Microbial carbon pump

5 Marine ecosystem carbon neutrality

6 Marine geological carbo n sequestration

7 Land & ocean coordinating carbon neutrality

Contents

1 Carbon peak&carbon neutrality

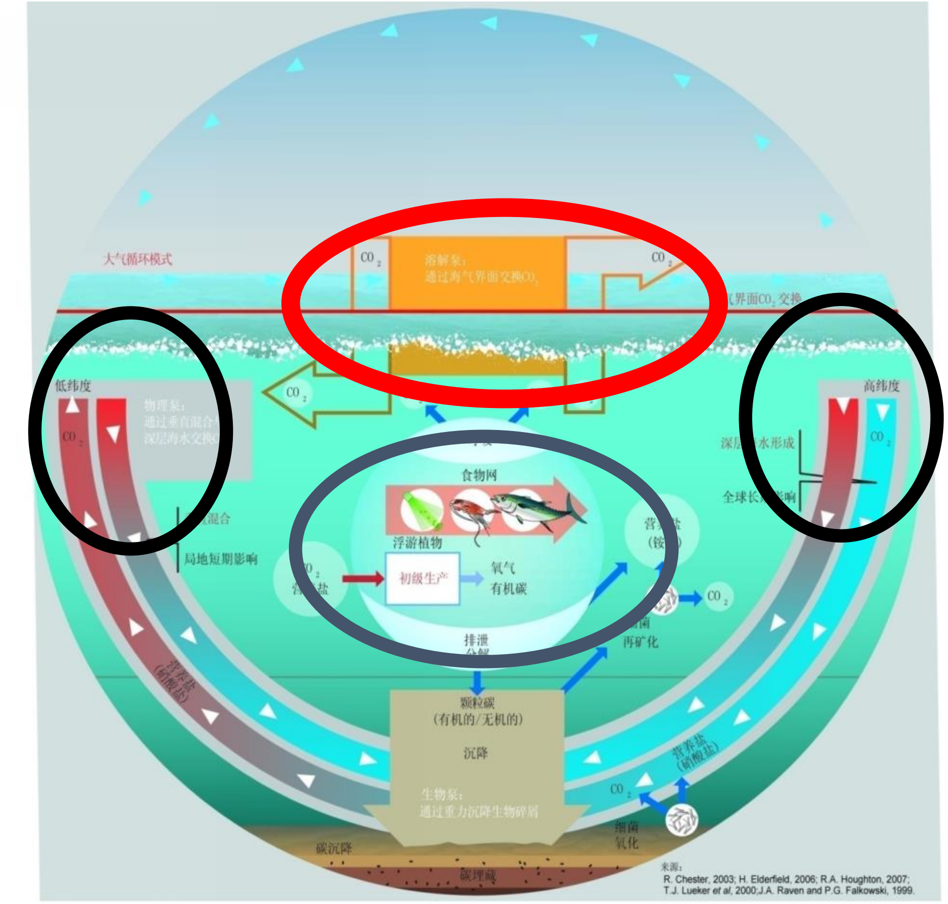
2 Marine carbon neutrality pathways

- Marine biological pump for increase carbon sink；
- Coastal wetlands emissions reduction & increase sink
- Fishery carbon sink；
- Marine ecosystems emissions reduction & increase sink
- Marine microbial carbon pump
- Marine geological carbon sequestration
- Land & ocean coordination

3 Marine phytoplankton carbon neutrality

- Carbon storage calculation
- Carbon sink calculation

3 Marine carbon cycling



Solubility pump: whereby the solubility of CO_2 increases with depth due to colder water at depth.

Biological pump: a major part of the process that draws down carbon from the atmosphere into the surface layers of the ocean, where carbon is dissolved in seawater, converted to particulate form through primary production, then consumed by pelagic biota, exported to depth, and/or sequestered in the deep sea

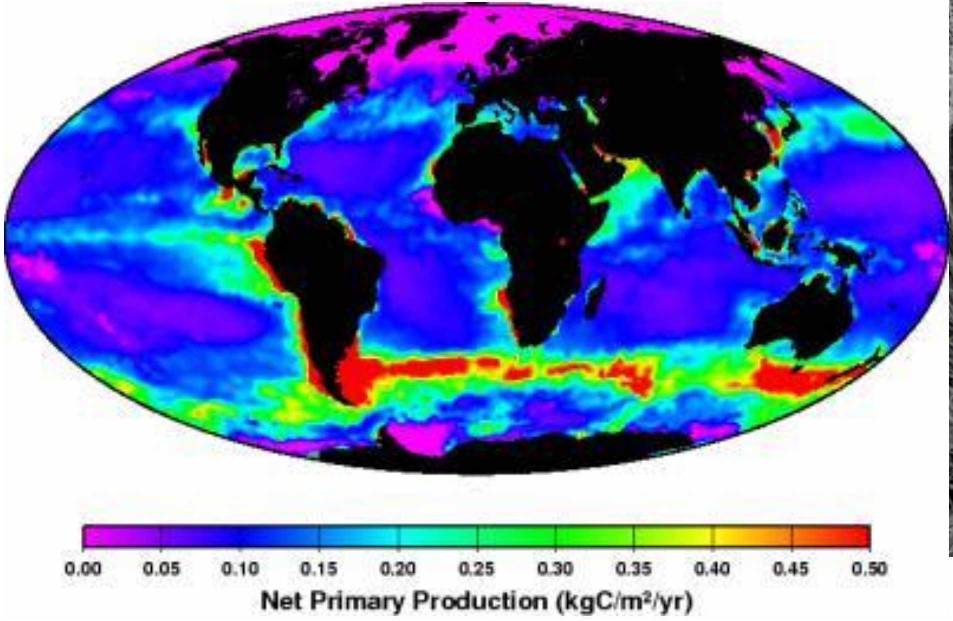
Continental pump: transporting carbon from shelf to adjacent deep oceans

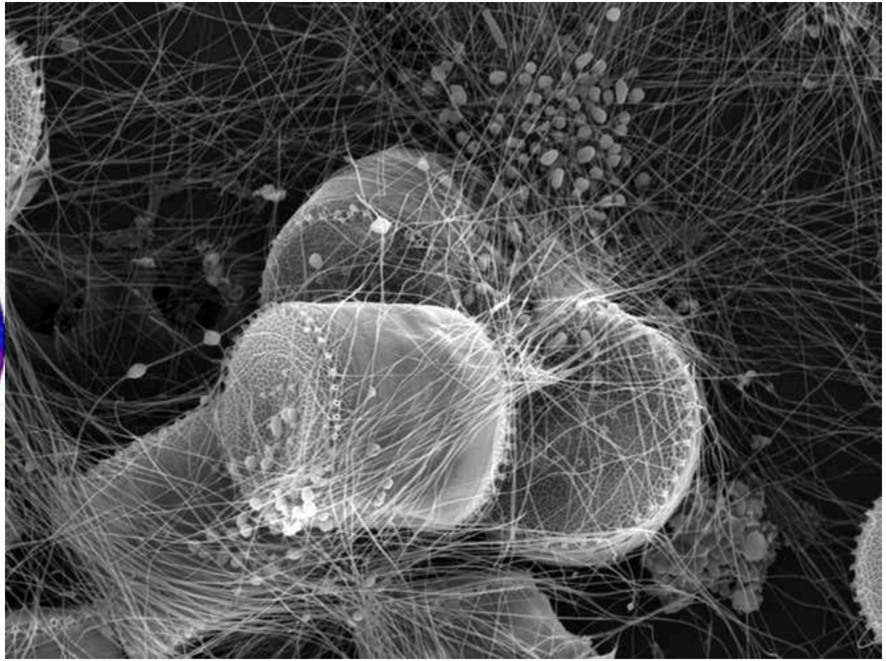
（Siegenthaler&Sarmiento,1993）

3 Phytoplankton vs. global change

Phytoplankton —— primary producers, start food chain, change CO_2 budget
Phytoplankton —— Changes in water dynamics can reach to the level of climate control (Dewar et al, 2006).

Global ocean biogenic particles: 3 GTC
Marine phytoplankton: 2.5 GTC



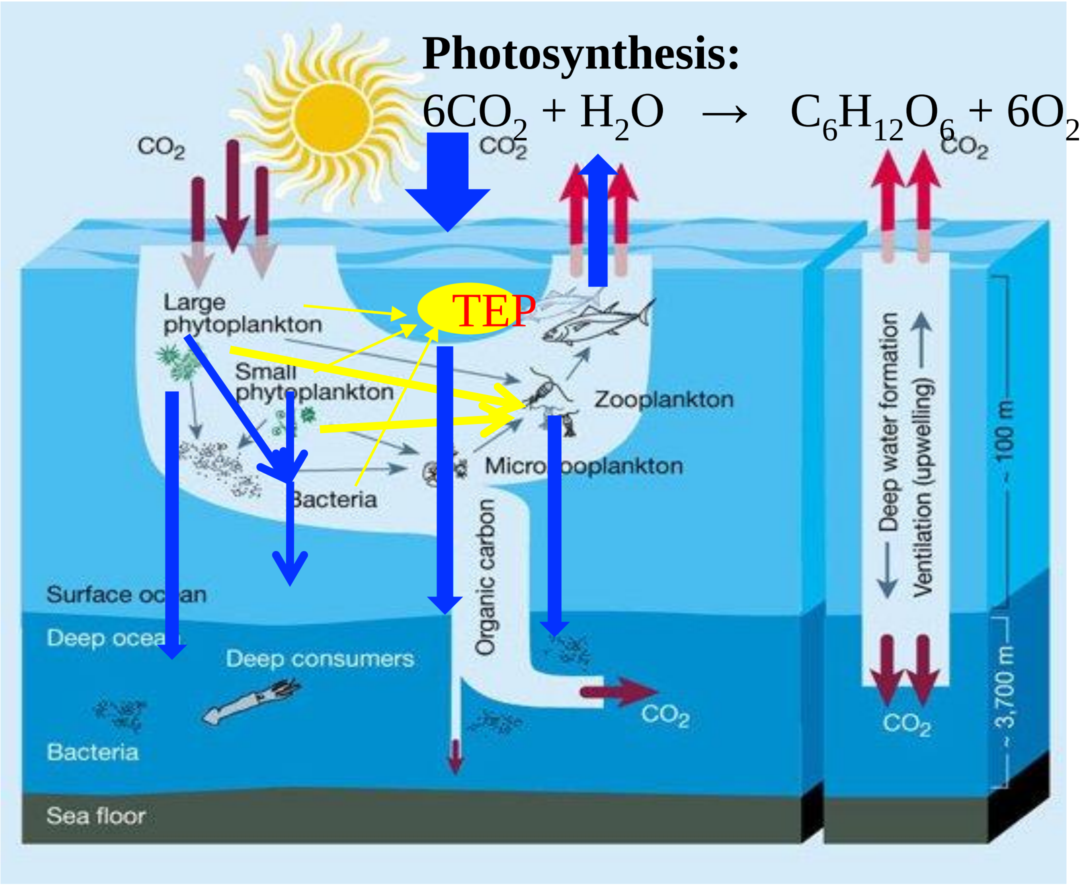


SEM graph of Vibrio attached on diatoms

3 Marine phytoplankton carbon sink pathways

Photosynthesis:

$$6CO_2 + H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$



Primary production

Phytoplankton sink

Zooplankton fecal pellets

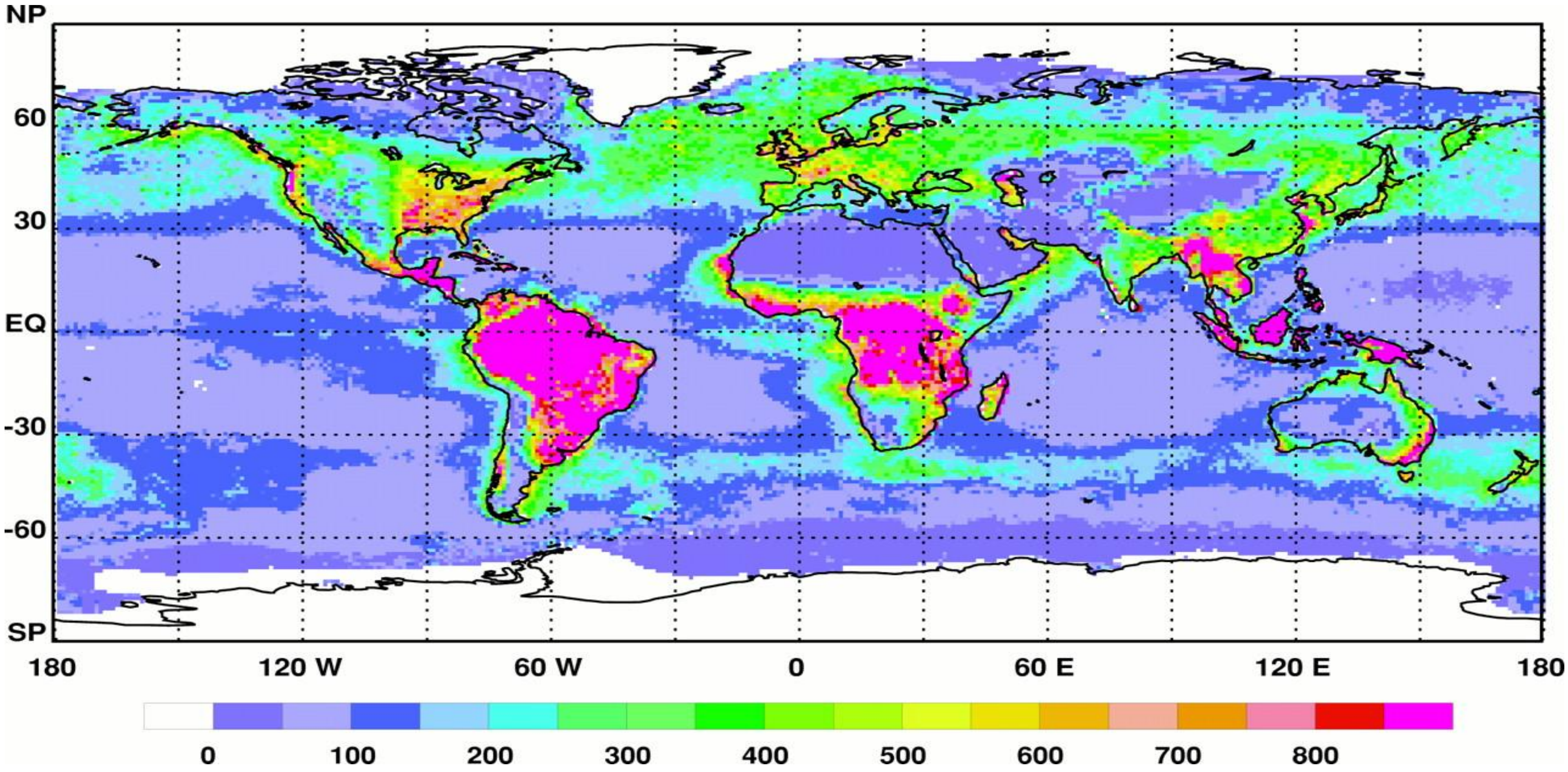
Classical food chain

DOC production & transform

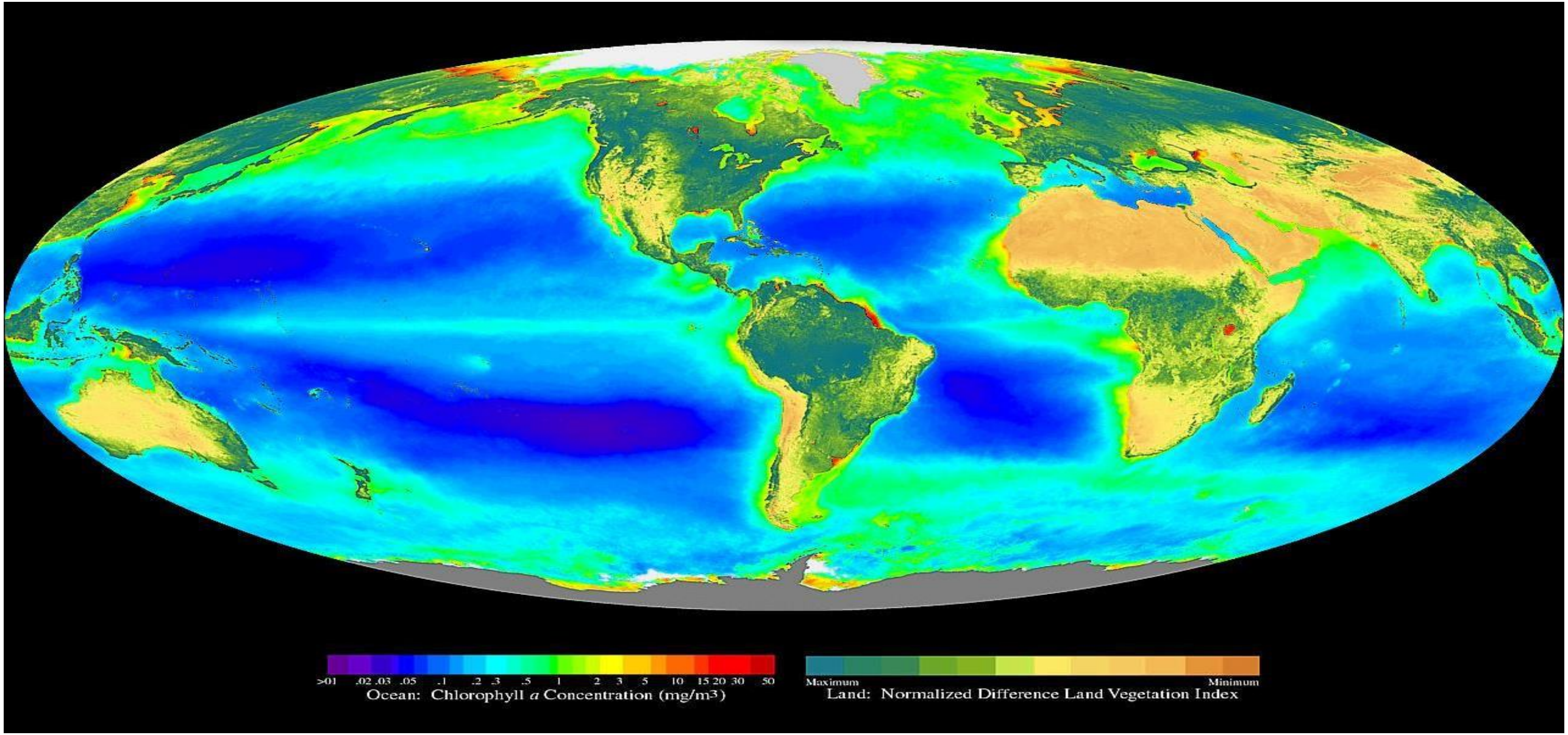
Transparent Exopolymer Particles

Sun，2011

3 Carbon fixation——Global net primary production



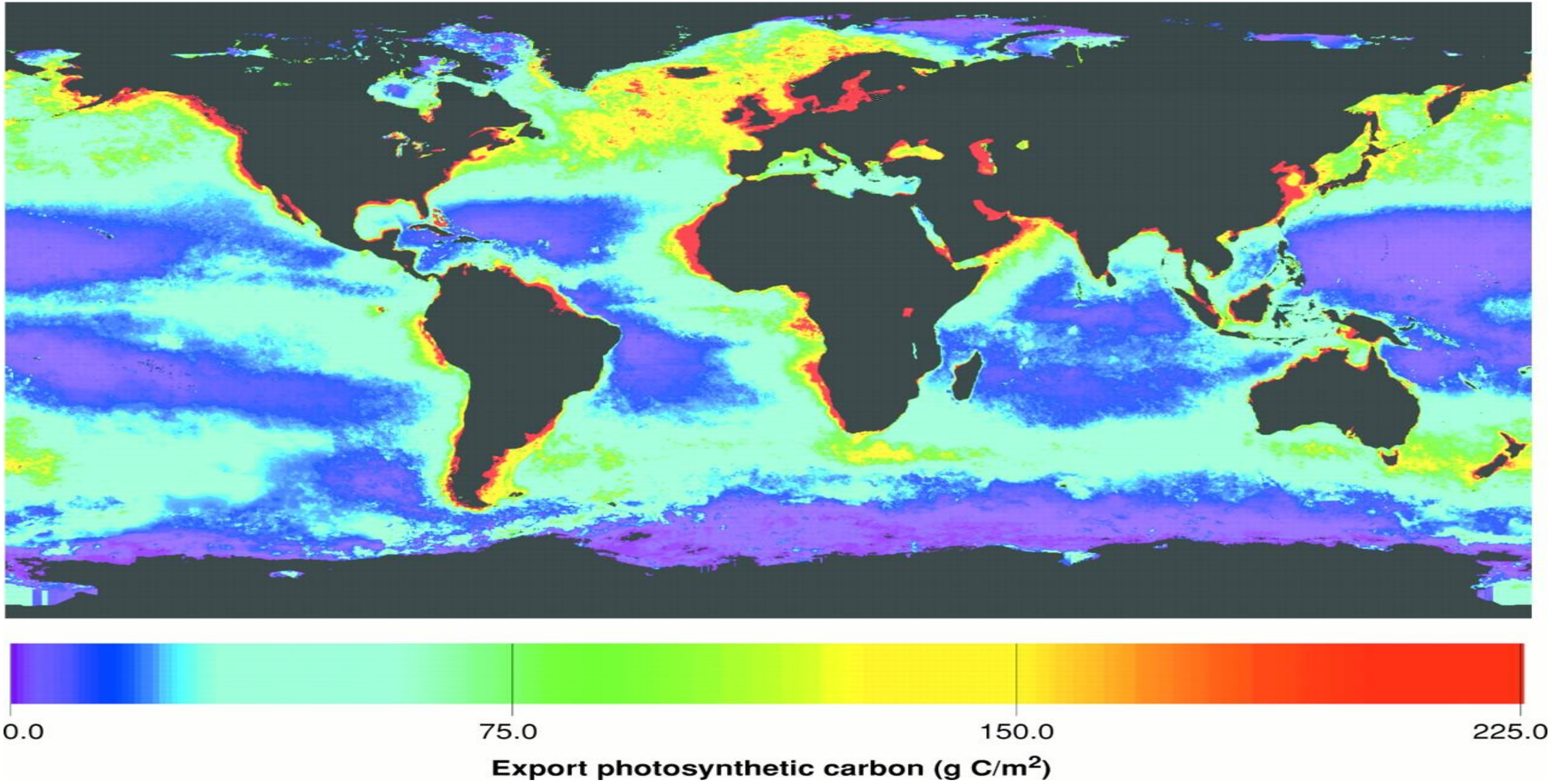
3 Carbon storage——
terrestrial plant *vs* marine plants~phytoplankton



The abundance distribution of photosynthetic plants in global ocean and land distribution

（derived from, NASA/Goddard Space Flight Center and ORBIMAGE）

3 Carbon sink——global average export production



3 Carbon storage——phytoplankton carbon estimates

1. Method 1: Chlorophyll *a*

Key point： C:Chl*a*
Merit： rapid, remote sensing
Defect： greatly affected by environmens

2. Method 2: Cell volume estimates

Key point： $C=a*V^b$
Merit： relatively accurate， species level
Defect： time-consuming， expertise

3. Method 3: Chemometrics

Key point： C:N:P=106:16:1
Merit： simple & rapid
Defect： inaccurate

(Sun,1997,2004)

Figure 1. Left: using an immersion thermometer inserted directly into the water-sampling bottle. Centre: YSI multiparameter probe for measuring temperature and salinity. Right: CTD (conductivity, temperature, depth) multiparameter probe attached to the winch of the boat before being cast.

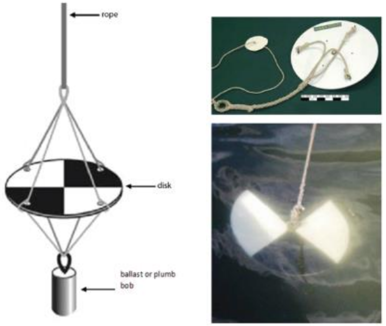


Figure 2. Various models and parts of a Secchi disk; view of a disk submerged in water with plenty of greenish pigments.

Figure 3. Left: plankton net with a cod end with a stopcock for unloading the sample. Right: plankton net with a cod end, or collection cup, and a weight attached for the descent into the water (model provided to participants in Project RLA/7/014).

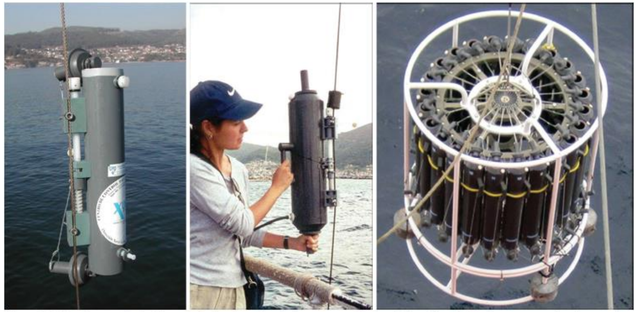
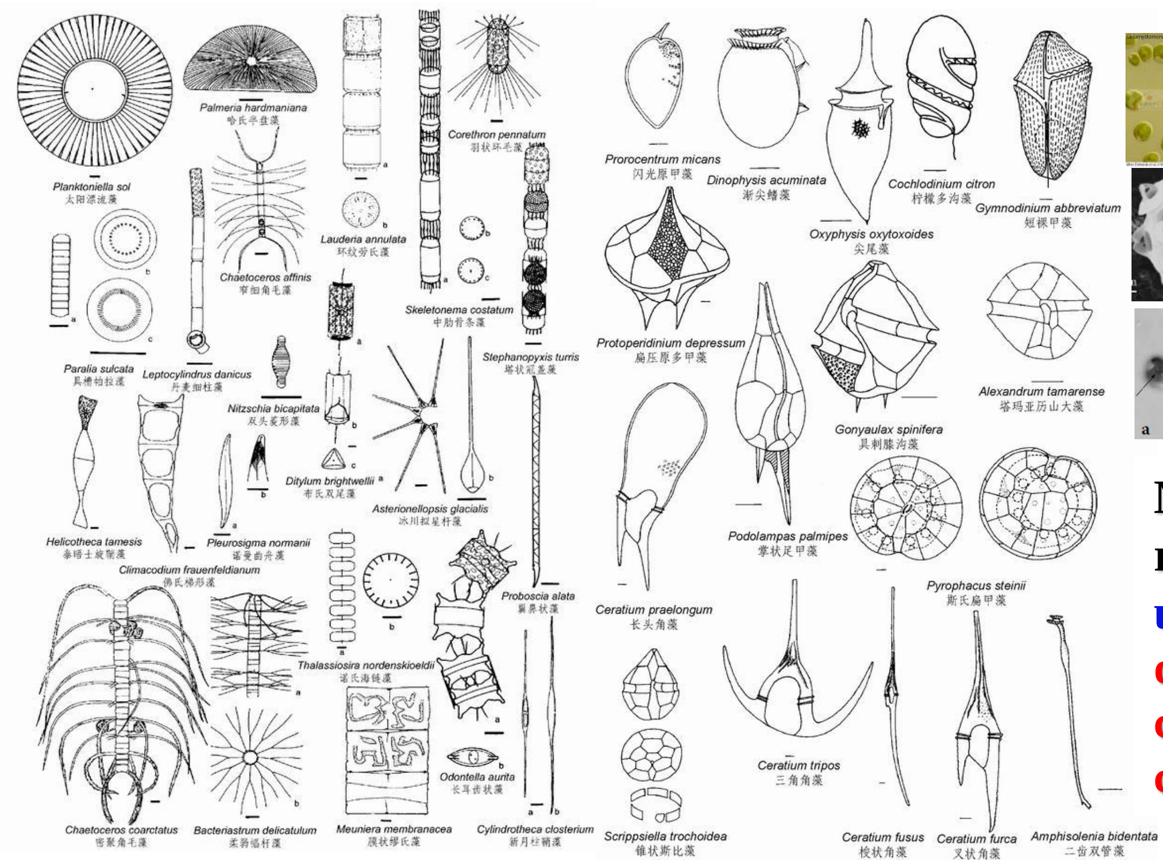
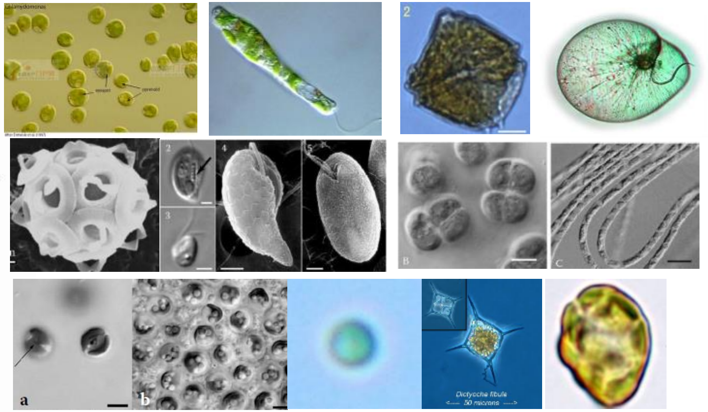


Figure 4. Left: water-sampling bottle ready for the descent, with its caps open. Centre: bottle retrieved after the messenger has been cast and raised. Right: rosette with 24 water-sampling bottles.

3 Phytoplankton cell morphology and cell size

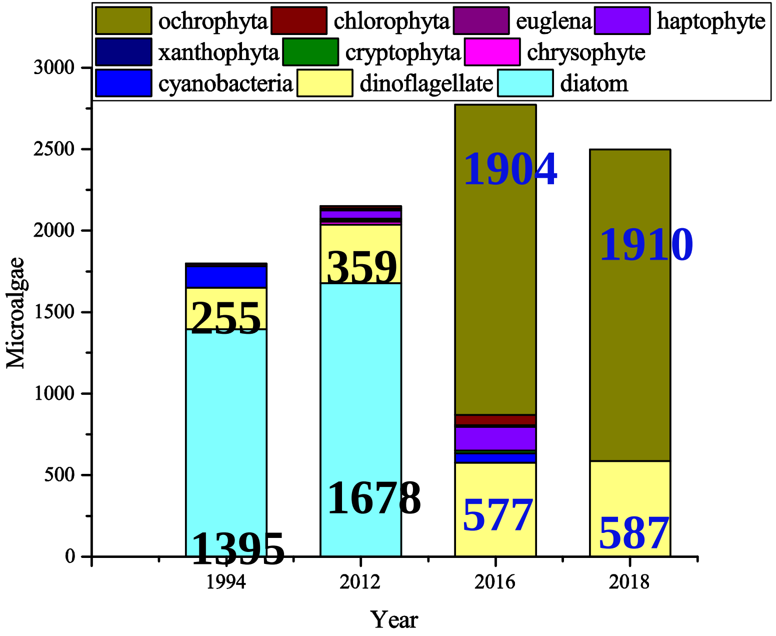


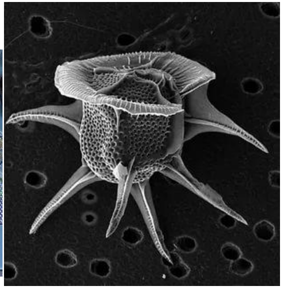


Marine phytoplankton size ranges:0.2~2000μm, unicellular, including diatoms、dinoflagellates、chrysophytes、cyanobacteria、chlorophytes、cryptomonas

(Sun, 2004)

3 Phytoplankton biodiversity in China seas



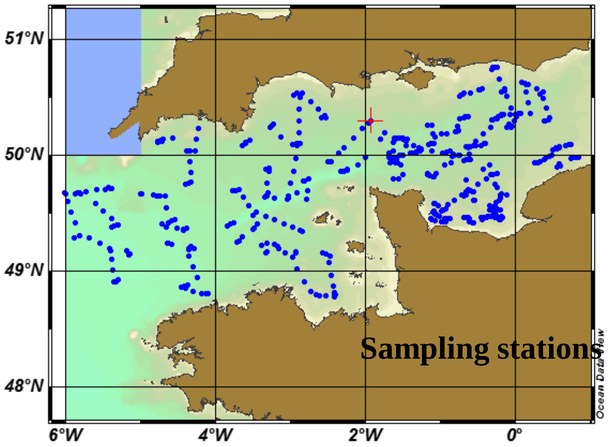


- ●Based on incomplete statistics: 2772 taxa, to 2016.
- ●Updates two phyla: Ochrophyta & Pyrrophyta (2788)。

Groups	Richness	China seas
Cyanophyceae	7500	57
Euglenophyceae	1500	10
Dinophyceae	2000	577
Chlorophyceae	2500	62
Crytophyceae	200	17
Prymensiophyceae	500	97
Bacillariophyceae	10000	1879
Chrysophyceae	1000	3
Raphidophyceae	27	4

(unpublished data of Sun Jun)

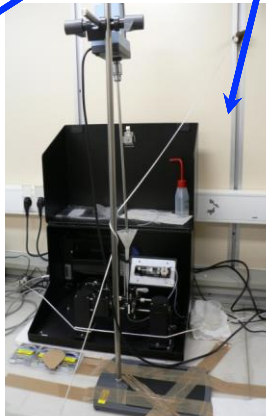
3 Innovative technology for integrated phytoplankton observation

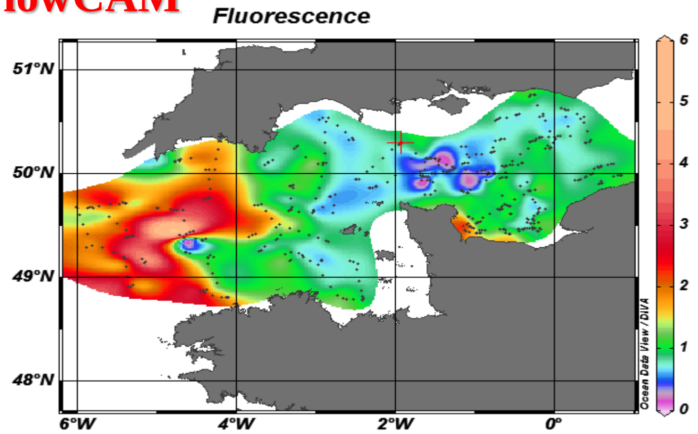


Aim: Application of high frequency resolution technology in ecosystem cruise (Biological resource assessment, research)

Traditional low resolution monitoring strategies are combined with high resolution analysis through in vivo recording innovation:

-Ferry-Box
-Spectrofluorometry
-FCM(flow cytometry)
- FlowCAM





3 Phytoplankton carbon storage methods

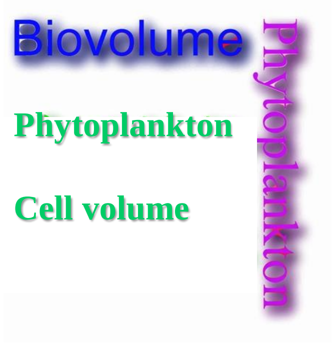
Phytoplankton cell volume & carbon conversion method

$$C = aV^{b}$$

Eppley *et al.* (1970)

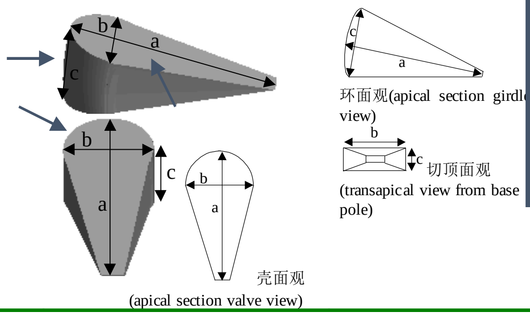
$$log_{10}C = 0.94 \cdot (log_{10}V) - 0.60$$ Diatoms

$$log_{10}C = 0.76 \cdot (log_{10}V) - 0.352$$ Others



Phytoplankton cell volume estimation

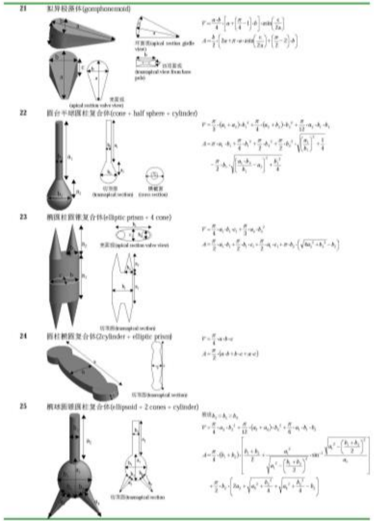
形状代码 (shape code)	形状示意 (simulated shape)	体积模型和表面积模型 (volume (V) and surface area (A) models)
21	拟异极藻体(gomphonemoid)	



$$V \approx \frac{a \cdot b}{4} \cdot \left[a + \left(\frac{\pi}{4} - 1 \right) \cdot b \right] \cdot \operatorname{asin}\left(\frac{c}{2a} \right)$$

$$A \approx \frac{b}{2} \cdot \left(2a + \pi \cdot a \cdot \operatorname{asin}\left(\frac{c}{2a} \right) + \left(\frac{\pi}{2} - 2 \right) \cdot b \right)$$

（孙军，1997；Sun，2003）



Sun J, Liu D Y. *Journal of Plankton Research*, 2003, 25(11):1331-1346

SCI citation more than 600 times； apply model for large scale computation

3 Critical parameter calculation & keystone species establish、phytoplankton functional group

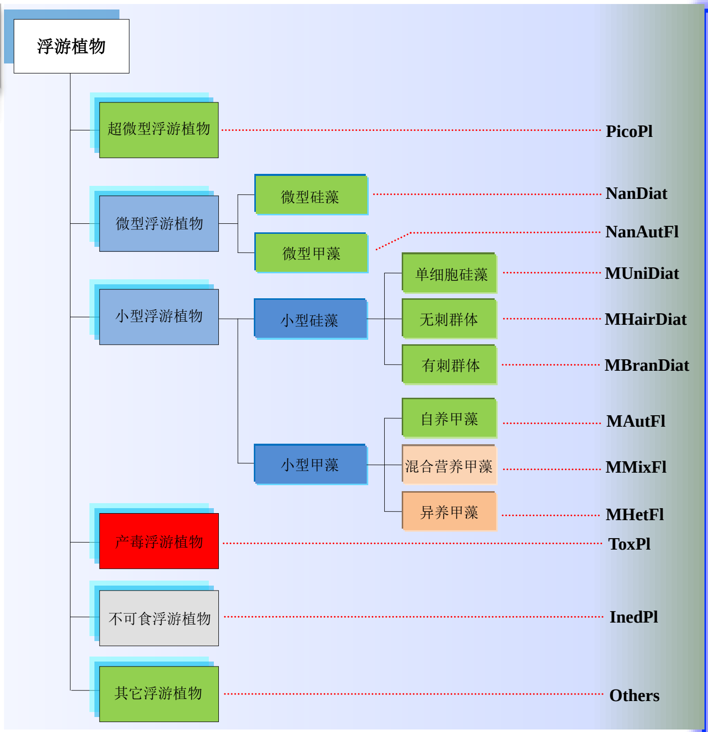
Phytoplankton carbon biomass calculation

$$Biomass_{int} = \sum_{i=1}^{n-1} \frac{B_i + B_{i+1}}{2} \times (D_{i+1} - D_i)$$

Criticality calculation

$$K_i = \frac{B_i}{B} \cdot f_i = \frac{b_i \cdot \sum_{j=1}^{n} c_{ij}}{\sum_{i=1}^{m} \left(b_i \cdot \sum_{j=1}^{n} c_{ij} \right)} \cdot f_i$$

(Sun, 2004)



~~超微型浮游植物（PicoPl）~~

~~微型硅藻（NanDiat）~~

~~微型自养鞭毛藻（NanAutFl）~~

小型自养甲藻（MAutFl）

小型混合营养甲藻（MMixFl）

小型异养甲藻（MHetFl）

小型单细胞硅藻（MUniDiat）

小型无刺群体硅藻（MHairDiat）

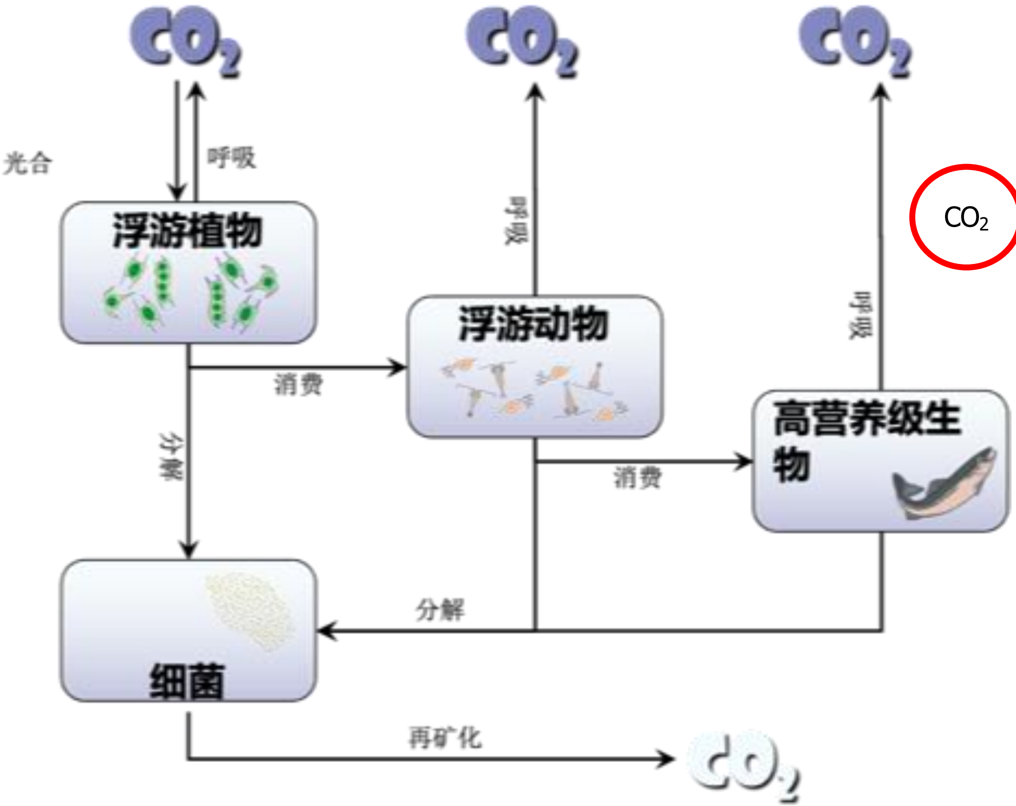
小型有刺群体硅藻（MBranDiat）

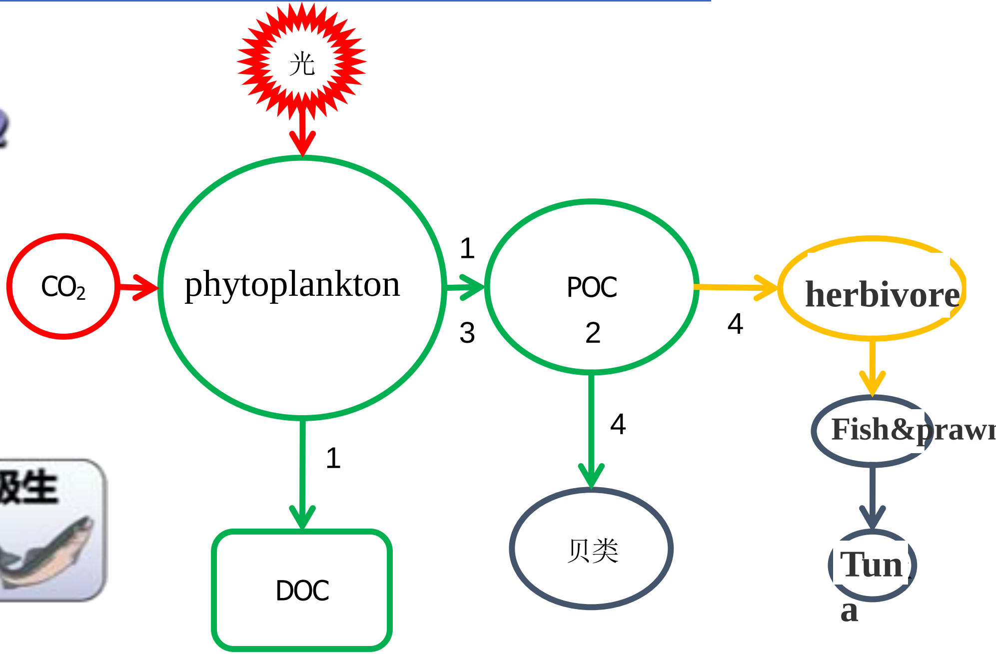
产毒浮游植物（ToxPl）

不可食浮游植物（InedPl）

其它浮游植物（Others）

3 Phytoplankton vs. food chain carbon sink





1. Primary production
2. Carbon biomass
3. Growth rate
4. Grazing rate

3 carbon fixation&storage——critical parameters for phytoplankton carbon calculation

1. **Phytoplankton carbon biomass（*C*）**

   carbon content of phytoplankton cell or community , the so-called “carbon storage”

   unit：ug C · L^{-1}

   $$P = \mu \cdot C_0$$

   $$C_t = C_0 e^{\mu t}$$

2. **Primary production（*P*）**

   Incremental carbon content per unit time in phytoplankton

   unit： ug C · L^{-1} · hr^{-1} or mg C · m^{-2} · d^{-1}

3. **Specific growth rate（*μ*）**

   The rate of phytoplankton change per unit time

   unit： d^{-1}

   $$\mu = \frac{1}{\delta t}\log_2 \frac{\mathrm{C:Chl}\,a + \dfrac{\delta C}{\mathrm{Chl}\,a}}{\mathrm{C:Chl}\,a}$$

4. **Specific grazing rate（*g*）**

   The change rate of phytoplankton death by herbivores per unit time

   unit： d^{-1}

   $$P_{td} = P_0 \cdot \mathrm{e}^{(\mu - d \times g)t}$$

(Sun, 2005, 2013)

3 Marine phytoplankton carbon sink based on species and community level

1 Primary production

2 Phytoplankton sinking

3 Zooplankton fecal pellets

4 Classical food chain

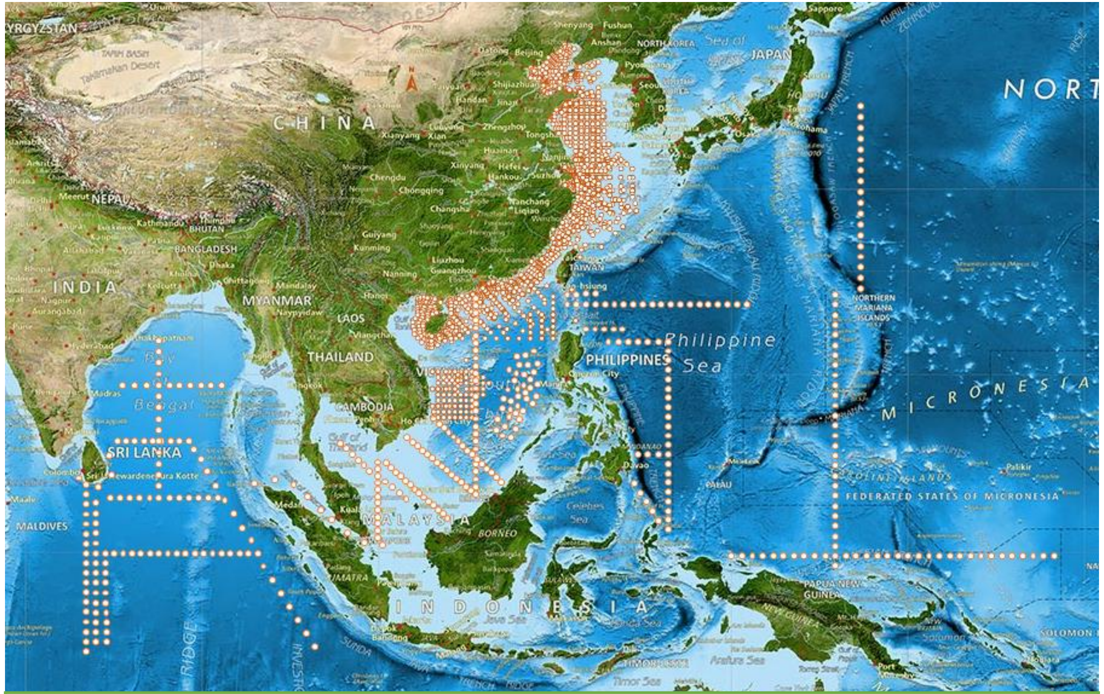
5 DOC production&transform

6 TEP


第31卷第18期 生态学报 Vol. 31, No. 18
2011年9月 ACTA ECOLOGICA SINICA Sep., 2011

海洋浮游植物与生物碳汇

孙 军

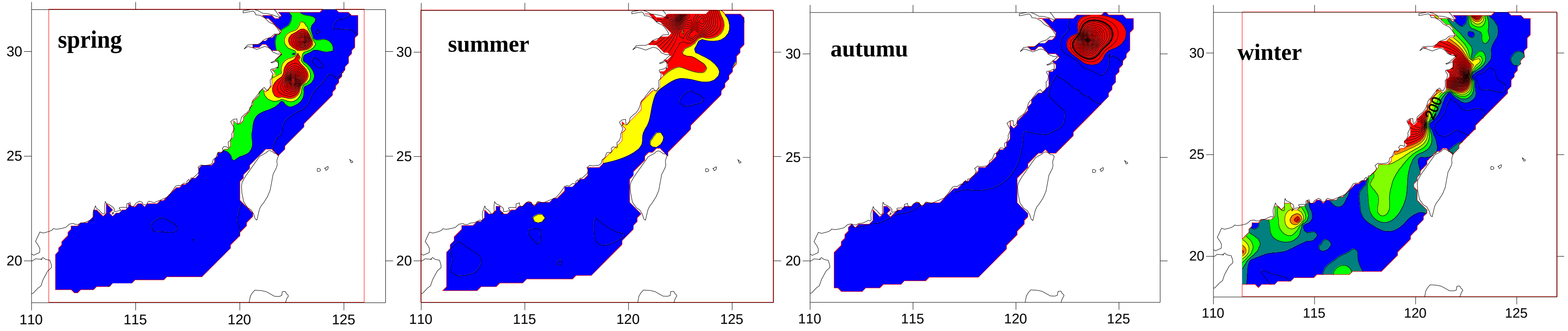


Phytoplankton carbon pool in China sea

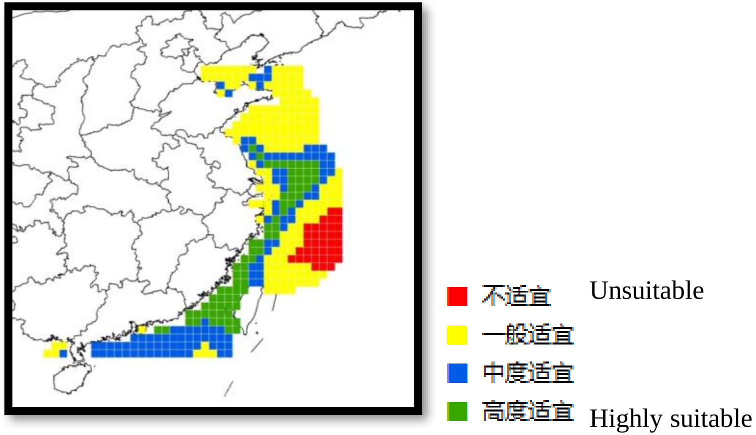
Since 1995, net samples in China sea more than 5000, seawater samples more than 25000。

Results as of December 2019

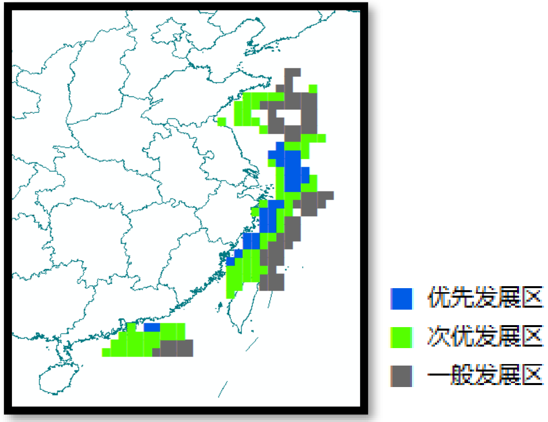
3 Phytoplankton carbon partition & function division in China seas



ECS&n-SCS phytoplankton carbon biomass patterns（unit:mg/m^3）

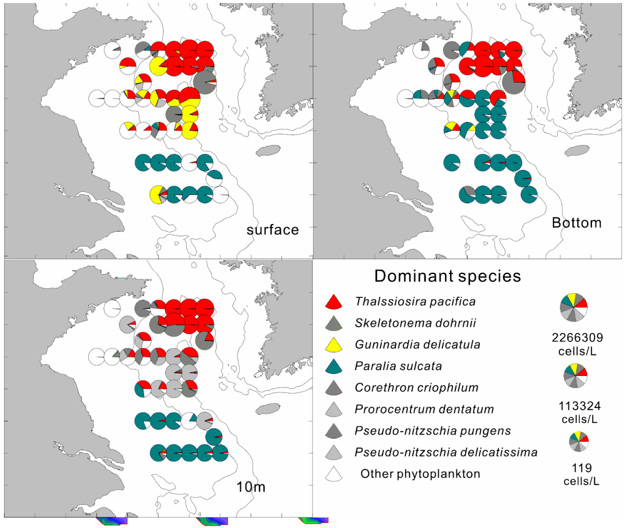


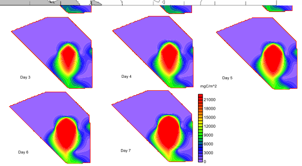
China's coastal water **carbon fixation division** map

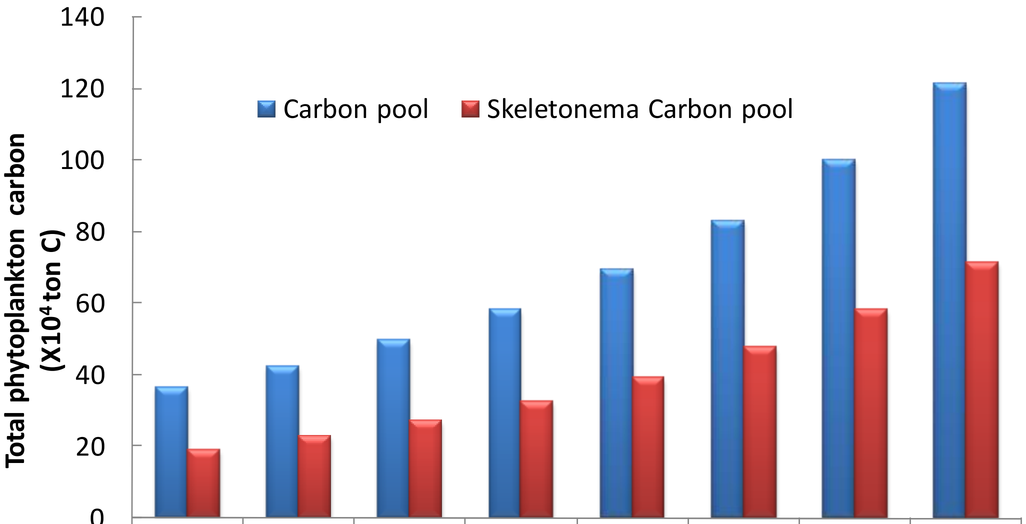


carbon fixation eco-types map

3 phytoplankton carbon accumulation in one 7 days spring bloom in the central Yellow Sea, China







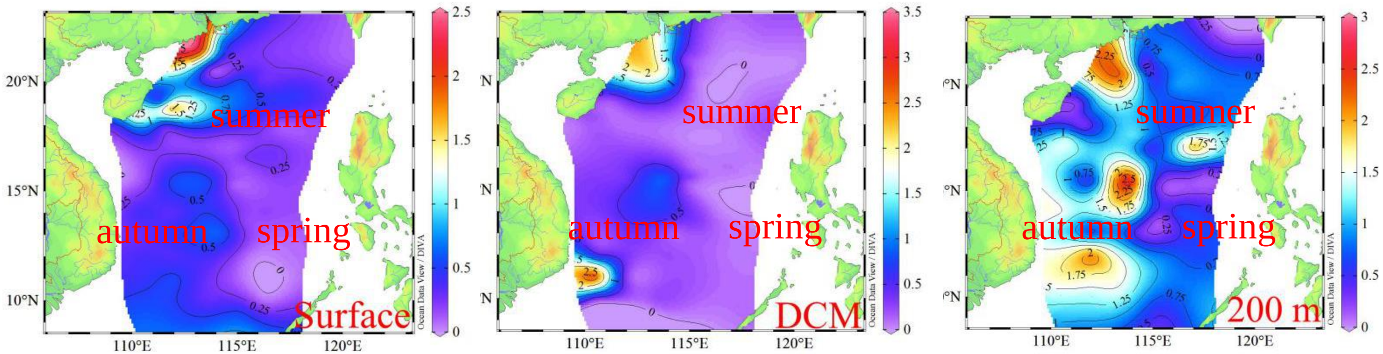
	d0	d1	d2	d3	d4	d5	d6	d7
Carbon pool	36.31	42.22	49.46	58.35	69.36	83.03	100.12	121.57
Skeletonema Carbon pool	19.19	22.72	27.06	32.45	39.16	47.55	58.08	71.37

date

Phytoplankton carbon stock Before bloom: 38 ten thousand tons of carbon, after bloom (7 days) : 140 ten thousand tons of carbon

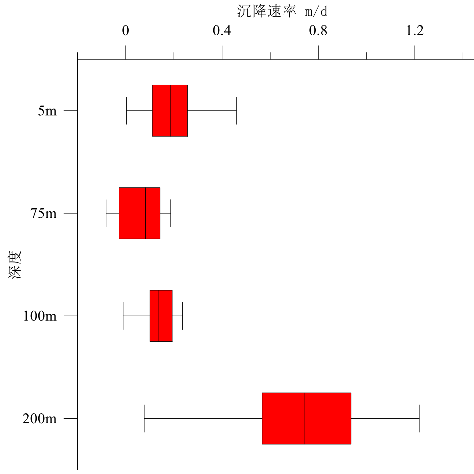
3 Seasonal phytoplankton, zooplankton fecal pellets & TEP sinking carbon flux

2011CB409804

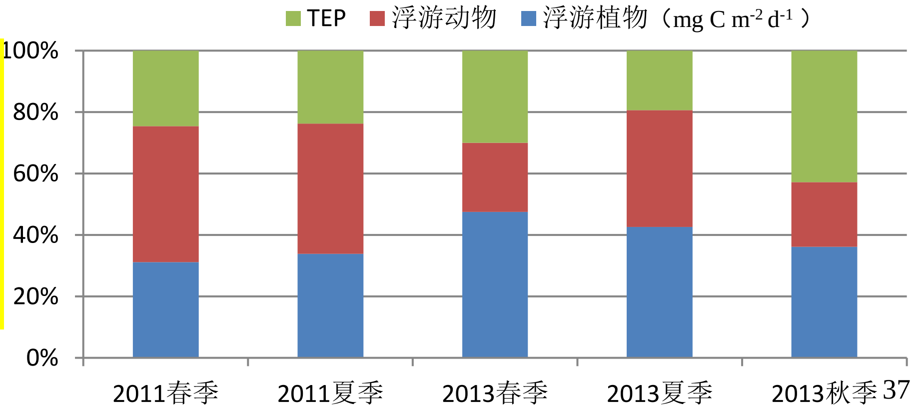


Phytoplankton sinking rates in 2016 w-SCS & 2017 c-SCS， NE-SCS (m/d)

(Mao & *Sun 2019, 2020)



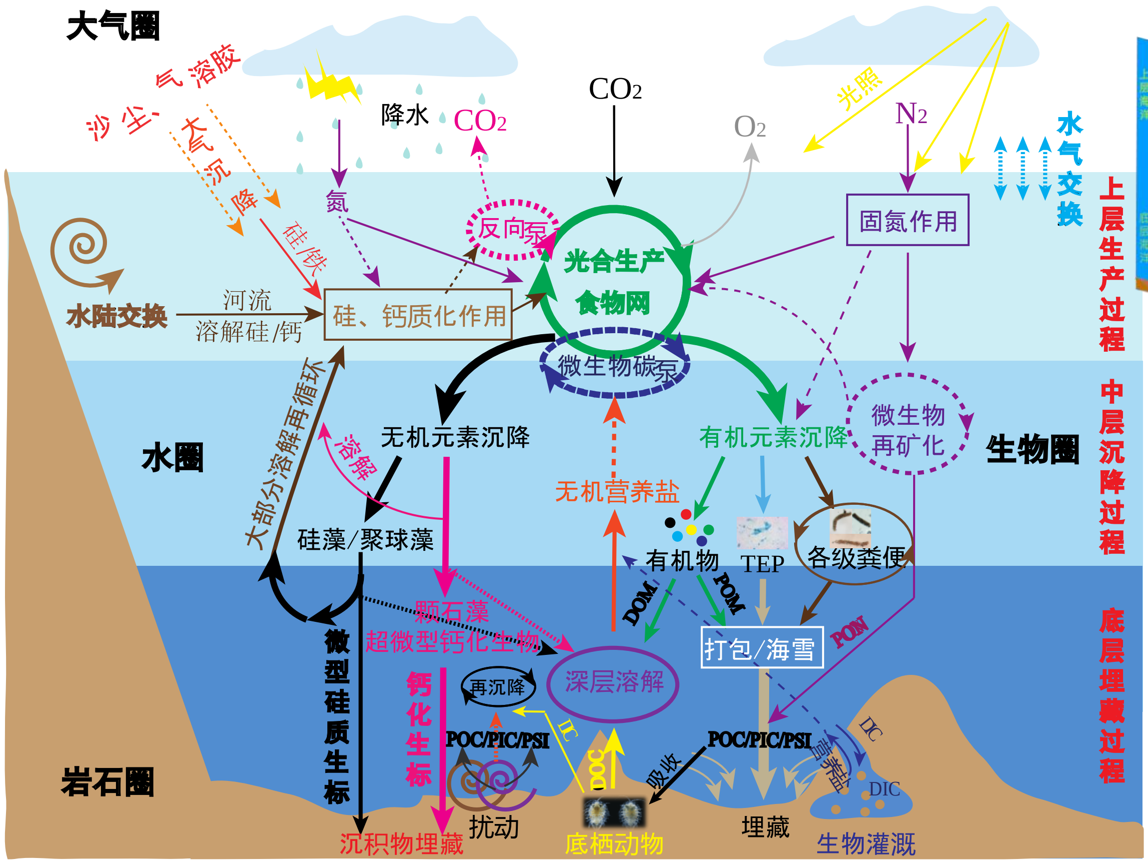
Carbon flux：
summer>spring
3 types of carbon flux:
phytoplankton 38.4%
Fecal pellets 33.4%
TEP 28.2%



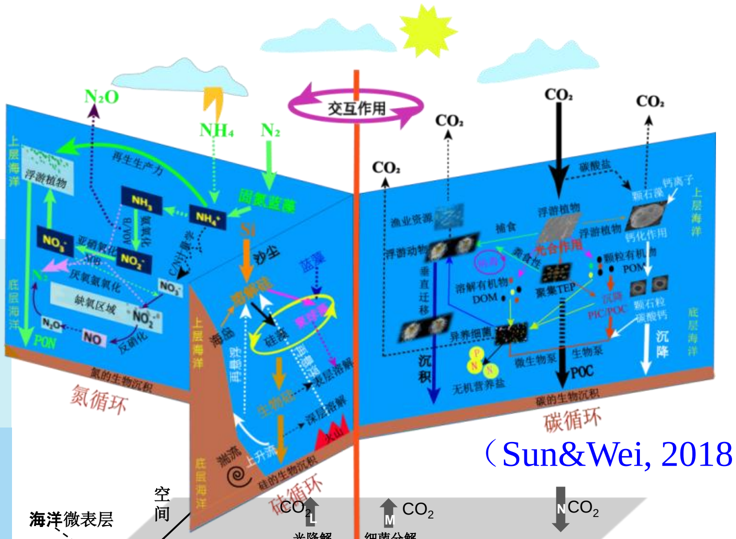
(Guo & *Sun 2019, 2020)

Sinking rates comparison：
RioMar>OceMar；
Rate in different layer s：
bottom>surface>DCM

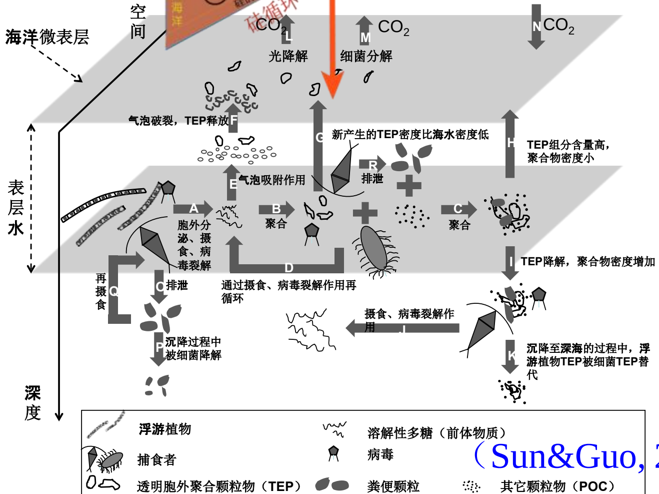
3 Biological carbon pump——new findings



(Sun & Chen 2016)



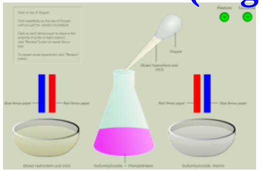
（Sun&Wei, 2018）

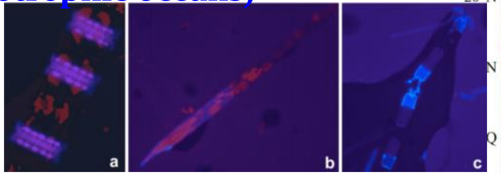


（Sun&Guo, 2019）

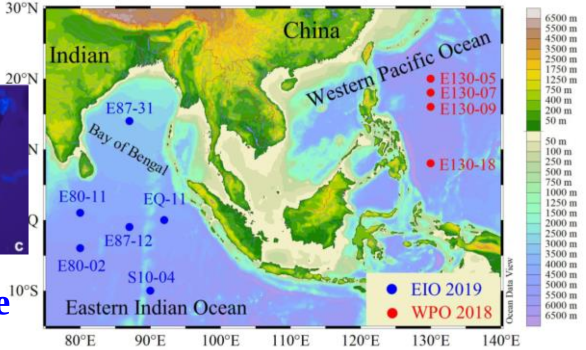
3 Role of picophytoplankton in ocean Si-C cycling

standing stocks of picophytoplankton in Si：>20-60% (oligotrophic oceans)

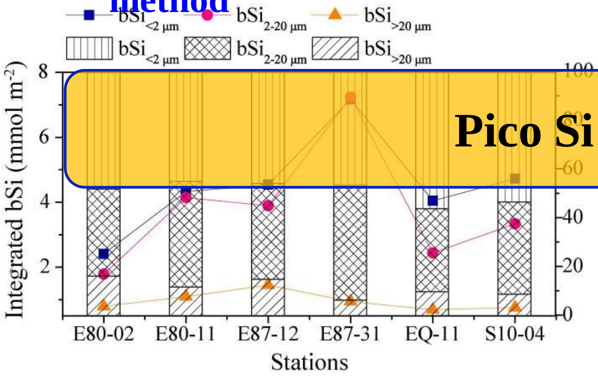




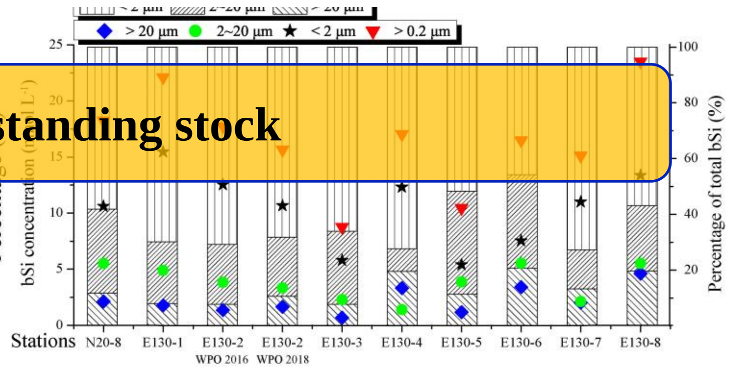
Two-step hot alkaline method **PDMPO fluorescence**

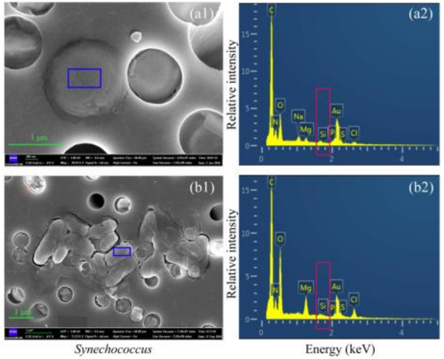


SEM-EDS



Pico Si standing stock





Synechococcus **–Si accounts for 1-8% of BSi;**

Total Si of global *Synechococcus* is 0.2 Tmol Si, accounts for 5-7%;

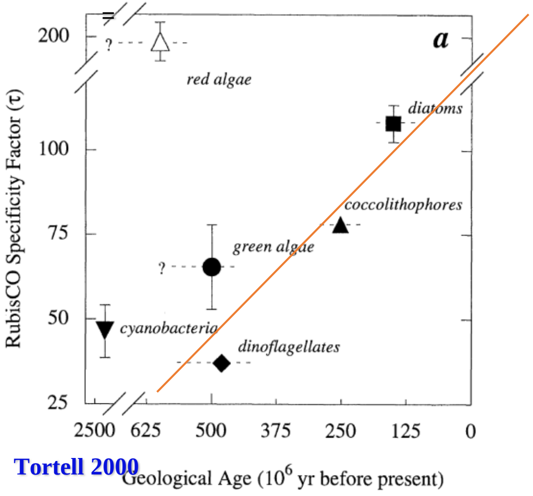
Siproduction of global *Synechococcus* : 15 Tmol Si a^{-1}, accounts for 5-8%

（Wei, & *Sun., 2021 PIO，Ecosystem, PIO, L&O）

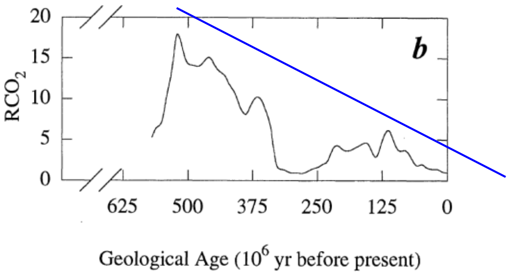
3 BCP increasing carbon sink——
increase phytoplankton carbon fixation efficiency

Ribulose bisphosphate carboxylase specific factor = $\frac{\text{Carboxylase activity}}{\text{Oxidase activity}}$

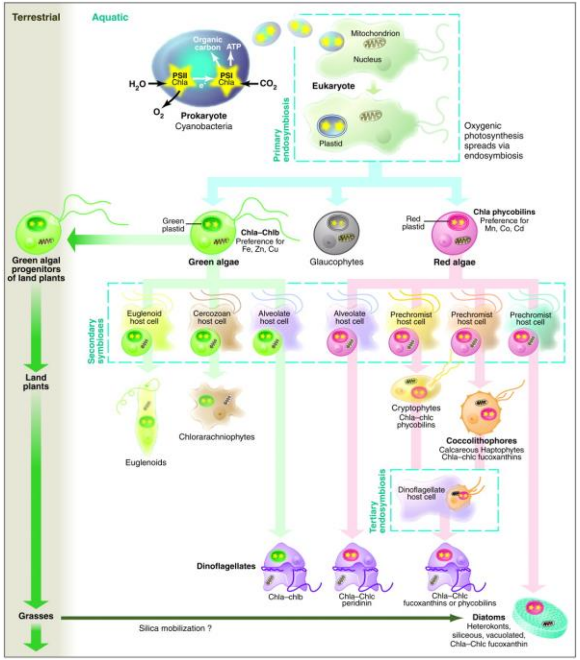
CO_2 absorption capacity is algae species-specific

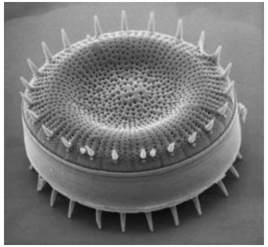


Tortell 2000



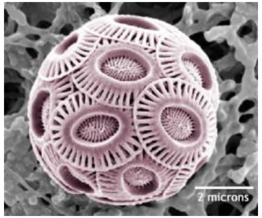
RCO_2=modern atmospheric CO_2



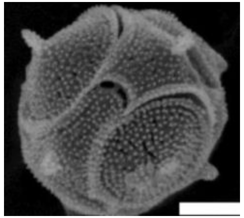


Diatoms

Synechococcus



Coccolithophores



Bolidophyceae

Summary

- **BCP is important and further study is necessary！！！**
- **Offshore carbon neutrality has a long way to go：5GTC, pathway：BCP, coastal wetland, fishery carbon sink, MCP, marine ecosystems, geological carbon sequestration, land& ocean coordinating;**
- **Carbon neutrality can start from land& ocean negative emissions： Estuarine eutrophication（proper N/P）→ecosystem carbon sink（benthos & fishery resource organism ～shorten food chain）**
- **Coastal carbon neutrality is focused on Artificial ecosystem operation, Biotechnology engineering is urgently needed in the future.**

Thanks for your attention

Sun Jun 18622736321