# MCS-CNS Annual Report 2021

The Mechanisms of marine carbon storage and

coupled carbon, nitrogen and sulphur cycles in response to global change (MCS-CNS)

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## 1. Selected highlights

### 1.a.i. Selected scientific highlights since last report

*Last report was submitted to SSC meeting, May/June 2020. Each highlight needs to be VERY short, bullet points, with a link to publication if applicable.*

- ✓ Aromatic hydrocarbon metabolism of methane anaerobic oxidation archaea ANME were found in the deep-sea cold spring (Liu et al., 2020).
- ✓ The first evidence of the preservation of a sub-seafloor cryptic sulphur cycle and The multiple sulphur isotope systematics of pyrite clearly reveal its genesis (Liu et al., 2020, EPSL).
- ✓ High-frequency Biogeochemical-Argo program revealed wintertime phytoplankton blooms developed during calm wind periods. This process generated remarkably high carbon export over winter, of which 80% or entirely were missed under low- frequency BGC-Argo program. (Xing et al., 2020, GRL)
- ✓ A cryptic methane cycle in sulfate-reducing sediments was found from the continental shelf of the northern South China Sea. Methylotrophic methanogenesis was the dominant methanogenic pathway. Methyl-compounds driven methane production drives a cryptic methane cycling and fuels AOM coupled to the reduction of sulfate and other electron acceptors. (Xu et al., 2020, EM)
- ✓ Wintertime $CO_2$ solubility along a north-to-south latitude gradient dominated the coastal acidification development. High-latitude Yellow Sea exhibits higher CO2 solubility in winter and longer respiration-product accumulations in warm seasons, leading to lower $\Omega_{arag}$ in the central Yellow Sea than those in the northern ECS. (Xiong et al., 2020, Frontiers in Marine Science)
- ✓ North Yellow Sea supplied additional DIP to the central Bohai Sea via wintertime water intrusion, balancing terrigenous excess DIN that was introduced in summer. Eutrophication in the central Bohai Sea will likely be enhanced by the large-scale accumulation of anthropogenic nitrogen in adjacent open oceans. (Zheng et al., 2020, EP)

- ✓ The temperature proxies $U^{K'}_{37}$ reflects annual mean SST with a slight bias toward the warm season. Terrestrial inputs appear to have a significant impact on LDI, TEXH86, and RI-OH proxies near the coast, leading to colder LDI- and TEXH86-derived temperatures but a warmer RI-OH temperature estimate. (Wei et al., 2020, Biogeosciences)

- ✓ $\#Rings_{tetra}$ increases with water depth in shelf areas due to more marine brGDGT production. Low $\#Rings_{tetra}$ values in deep sea sediments are not soil signal but due to low pH in situ. BrGDGTs in deep sea sediments with little terrestrial source have the potential to reconstruct bottom water pH. (Zhang et al., 2020, GPC)

- ✓ The LDI proxy is calibrated for the tropics using South China Sea surface sediments. LDI values are negatively correlated with SST at temperatures above 27 °C. This new LDI calibration is well correlated with archaeal lipid temperature proxies. (Yang et al., 2020, OG)

- ✓ Long chain 1,14-diols may reflect long-term accumulation of Proboscia productivity. 1,14-diol records can indicate upper water stratification in the study area. 1,15-$C_{32}$ diol may be used as a proxy for riverine organic matter input. (Zhu et al., 2020, Ecological Indicators)

- ✓ Prolonged warm SST is mainly associated with the $CO_2$ "overshoot", induced by enhanced recovery of Atlantic meridional overturning circulation. Earlier drop in thermocline water temperature is mainly linked to reduced heat transport from the surface to the subsurface ocean due to the weakened winding stirring. (Dong et al., 2020, GRL)

## 1.a.ii. Selected scientific highlights over last 5 years *(2016-2021)*

- ✓ A series of work has been carried out on the microbial metabolism related to the marine carbon, nitrogen and sulfur cycle: (1) Through the enrichment and cultivation of deep-sea sediments, it has been found that "deep archaea" have organic and autotrophic metabolic functions, that is, "Bathyarchaeota" is an important participant in the degradation of lignin in marine sediments. At the same time, this important discovery of " Bathyarchaeota " that can degrade lignin will provide new ideas and means for the utilization of refractory substances and the production of green energy (Yu et al., 2018, PNAS). A strong correlation was found between the bathyarchaeotal abundance and the content of total organic carbon (TOC), suggesting an important role of Bathyarchaeota in organic matter remineralisation in the sediments of SCS (Yu et al., 2017, EMR).

- ✓ Three different kinds of physical forcing, upwelling, aerosol deposition, and monsoonal Influences lead to the enhancement of mesopelagic sinking particle fluxes in the northwestern South China Sea (Zhang et al., 2019, JGR ocean). A permanent subsurface Chl a maximum (SCM) in the depth range of 48 to 96 m in the central basin of the SCS using observations from two Bio-Argo floats. In the northern basin, the SCM disappeared in winter, replaced by enhanced surface layer phytoplankton with high Chl a. A combination of strong wind mixing, surface cooling, Kuroshio water intrusion, and horizontal advection caused the winter surface phytoplankton bloom in the north (Zhang et al., 2017, JGR ocean). Surface variability of chlorophyll-a at seasonal scale was found to be highly modulated by the photoacclimation process. The mixing-induced entrainment played an important role in the vertical redistribution of particles, especially during the winter bloom period in the northern SCS. Both the physical entrainment and photoacclimation were found to modulate the vertical distributions of chlorophyll-a and particles in an ACE (Xing et al., 2019, JGR Ocean). High-frequency Biogeochemical-Argo program revealed wintertime phytoplankton blooms developed during calm wind periods. This process generated remarkably high carbon export over winter, of which 80% or entirely were missed under low-frequency BGC-Argo program (Xing et al., 2020, GRL).

- ✓ The bioavailability of coastal SDOM would directly influence the carbon budget at sediment-water interface, since we found that resuspension of labile SDOM into overlying seawater may weaken the role of sediment as a net sink of carbon (Cai et al., 2019, JGR). Coastal bacterioplankton are able to quickly utilize and transform lysis products of picocyanobacterial. Bacterial community varies with changing chemodiverisity of DOM. Viral-induced dissolved organic matter released from picocyanobacterial generated a complex labile DOM pool, which was converted to a rather stable DOM pool after microbial processing in the time frame of days to weeks (Zhao et al., 2019, ISME).

- ✓ Through the screening of marine microorganisms and special functional enzymes and the analysis of the mechanism of action, hundreds of strains of cultivable bacteria with hydrocarbon degradation function were isolated from the sediments of the Pearl River Estuary in the South China Sea and the Yangtze River Estuary in the East China Sea. Those findings provide important support for environment protection.

- ✓ Through a systematic survey of the sulfate reduction zone of sediments in the northern slopes of the South China Sea, we discovered the "hidden" microbial methane production pathway (Zhuang et al., 2019, Limnology and Oceanography). This discovery broke through the anaerobic oxidation (AOM) and the production of methane in the sediments.

- ✓ The ammonia oxidization (AO) inferred by lipid biomarkers of *Thaumarchaeota* in South China Sea for the past 160 kyr exhibited intensification in the interglacials, and moreover, showed strong precessional cycles with enhancements at the precessional maxima when boreal winter insolation was the highest (Dong et al., 2019, EPSL). The ammonia oxidizing archaea (AOA) record varied in line with isotope record of organic nitrogen ($\delta^{15}N_{org}$) that is modulated by the strength of diazotroph $N_2$ fixation (NF), suggesting a close coupling of increased AO with enhanced NF during periods of weak east Asian winter monsoon (EAWM) and hence increase of upper water stratification. AO intensification, a step of a series of dissolved oxygen consuming processes, is hereby hypothesized to encourage NF when the EAWM weakens. This result might be a reference for the future NF trend in the current situation of enhanced ocean deoxygenation due to global warming.

- ✓ Observed monthly decline in subsurface-water pH and aragonite saturation state from spring to autumn in the North Yellow Sea (Li et al. 2018. Continental Shelf Research), and explored seasonal acidification in the Yellow Sea (Chen et al. 2018. Science China Earth Sciences). Wintertime $CO_2$ solubility along a north-to-south latitude gradient dominated the coastal acidification development. High-latitude Yellow Sea exhibits higher CO2 solubility in winter and longer respiration-product accumulations in warm seasons, leading to lower $\Omega_{arag}$ in the central Yellow Sea than those in the northern ECS (Xiong et al., 2020, Frontiers in Marine Science).

- ✓ Conceptual model for the formation of summer hypoxia in bottom waters off the Changjiang Estuary. Under optimal conditions of light and nutrients, diatom blooms may form, with high primary production in surface waters and large fluxes of rapidly sinking biogenic silica and labile organic carbon. Other potentially significant physical and biogeochemical processes include riverine input of nutrients; aggregation, flocculating, and desorption during the mixing of river and marine waters; deposition and resuspension of fluid muds; respiration associated with resuspended sediments; exchanges oxygen across the sediment-water interface; and intrusion (upwelling) of Shelf Bottom Water. Surface sediments generally consist of sand in the inner estuary, silt and clay just offshore, and sand again on the outer shelf (Wang et al., 2017, Limnology and Oceanography).

- ✓ It is documented that the most severe faunal mass extinction in the oceans of 252 million years ago occurred as a pattern of two episodes, and was associated with abnormal biogeochemical cycles of carbon, nitrogen and sulfur. The first episode was associated with increases in red algae and nitrogen-fixing bacteria along with evidence for enhanced wildfires and elevated soil erosion, suggesting that terrestrial events contributed, partly if not wholly, to marine ecosystem collapse. The second episode was associated with expansions of green sulfur bacteria, nitrogen-fixing bacteria, and acritarchs coinciding with climatic hyperwarming, ocean stratification, and seawater acidification. Elevated temperatures may have been the trigger for marine ecosystem changes during the second episode that had existed for >200. It appears the oceans changed from coupled carbon and nitrogen cycles during the first episode to coupled carbon, nitrogen and sulfur cycles during the second episode which led to the more severe marine ecosystem collapse. Based on patterns of microbial community change during this ancient crisis, the present-day Earth can be inferred to be at a stage equivalent to the precursor of a major bio-crisis, and that continued environmental pressures are likely to lead to more profound and disruptive changes to the Earth's biosphere. This work was published in Earth and Planetary Science Letters (Xie et al., 2017, EPSL).

## 1.b. Publications since last report

*Please add all publications since last report to the table below (see notes for details on "Class" and "Activity" fields).*

| ***Publication*** *with DOI* | ***Class 1, 2, 3*** | ***Activity**** |
|---|---|---|
| 1. Ye, J., Lin, D., Zhang, M., Lin, T.H., Sun, J. & Tang K.* (2020). Paracoccus aurantiacus sp. nov., isolated from shallow-sea hydrothermal systems off Kueishantao Island. Int. J. Syst. Evol. Microbiol. 70:2554–2559. doi: 10.1099/ijsem.0.004068. | *3* | |
| 2. Zhang Q., Lin D., Ye J., Lin T.H., Li C., Yu L., Lin H., Sun Q., & Tang K.* (2020). Yeosuana marina sp. nov., isolated from shallow-sea hydrothermal systems off Kueishantao Island. Int. J. Syst. Evol. Microbiol. doi: 10.1099/ijsem.0.004525. | *3* | |
| 3. Ladigbolu, I. A., Li, B. H., Li, H. L., Wiesner, M. G., Yu, Z. F., Zhang, J. J., Sun, L., Ran, L. H., Ye, Y. & Chen, J. F. Fluxes and isotopic composition of planktonic foraminifera off Hainan Island, northern South China Sea: Implications for paleoceanographic studies. *Palaeoworld* 29, 636-647, doi:10.1016/j.palwor.2019.07.006 (2020). | *3* | |
| 4. Ma, C. L., Coffinet, S., Lipp, J. S., Hinrichs, K. U. & Zhang, C. L. Marine Group II Euryarchaeota Contribute to the Archaeal Lipid Pool in Northwestern Pacific Ocean Surface Waters. *Frontiers in Microbiology* 11, doi:10.3389/fmicb.2020.01034 (2020). | *3* | |
| 5. Tan, S. R., Zhang, J. J., Li, H. L., Sun, L., Wu, Z. Z., Wiesner, M. G., Zheng, H. & Chen, J. F. Deep Ocean Particle Flux in the Northern South China Sea: Variability on Intra-Seasonal to Seasonal Timescales. *Frontiers in Earth Science* 8, doi:10.3389/feart.2020.00074 (2020). | *3* | |
| *6.* Tang, K. Chemical Diversity and Biochemical Transformation of Biogenic Organic Sulfur in the Ocean. *Frontiers in Marine Science* 7, doi:10.3389/fmars.2020.00068 (2020). | *3* | |
| *7.* Chen, S. Z., Wang, P., Liu, H. D., Xie, W., Wan, X. S., Kao, S. J., Phelps, T. J. & Zhang, C. L. Population dynamics of methanogens and methanotrophs along the salinity gradient in Pearl River | *3* | |

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| Estuary: implications for methane metabolism. *Applied Microbiology and Biotechnology* 104, 1331-1346, doi:10.1007/s00253-019-10221-6 (2020). | | |
| *8.* Zhang, Q. F., Ye, J. N., Yu, L. M., Lin, D. & Tang, K. Serinicoccus hydrothermalis sp. nov., isolated from shallow-sea hydrothermal systems off Kueishantao Island. *International Journal of Systematic and Evolutionary Microbiology* 70, 3139-3144, doi:10.1099/ijsem.0.004145 (2020). | *3* | |
| *9. Xing, X., Wells, M. L., Chen, S., Lin, S. & Chai, F. Enhanced Winter Carbon Export Observed by BGC-Argo in the Northwest Pacific Ocean. Geophysical Research Letters, e2020GL089847 (2020).* doi:10.1029/2020GL089847 | *3* | |
| *10.* Liu, W. N., Wu, Z. J., Wu, S. N., Wei, J. G., Peng, X. T., Li, J. T. & Wang, Y. Q. Pore-water dissolved inorganic carbon sources and cycling in the shallow sediments of the Haima cold seeps, South China Sea. *Journal of Asian Earth Sciences* 201, doi:10.1016/j.jseaes.2020.104495 (2020). | *3* | |
| *11.* Wang, Y. Z., Wegener, G., Ruff, S. E. & Wang, F. P. Methyl/alkyl-coenzyme M reductase-based anaerobic alkane oxidation in archaea. *Environmental Microbiology*, doi:10.1111/1462-2920.15057. | *3* | |
| *12.* Xu, L., Zhuang, G. C., Montgomery, A., Liang, Q. Y., Joye, S. B. & Wang, F. P. Methyl-compounds driven benthic carbon cycling in the sulfate-reducing sediments of South China Sea. *Environmental Microbiology*, doi:10.1111/1462-2920.15110. | *3* | |
| *13.* Shen, X. Q., Wang, X. Z., Huang, T. T., Deng, Z. X. & Lin, S. J. Naphthoquinone-Based Meroterpenoids from Marine-Derived Streptomyces sp. B9173. *Biomolecules* 10, doi:10.3390/biom10081187 (2020). | *3* | |
| *14.* Liu, J. R., Pellerin, A., Izon, G., Wang, J. S., Antler, G., Liang, J. Q., Su, P. B., Jorgensen, B. B. & Ono, S. The multiple sulphur isotope fingerprint of a sub-seafloor oxidative sulphur cycle driven by iron. *Earth and Planetary Science Letters* 536, doi:10.1016/j.epsl.2020.116165 (2020). | *3* | |
| *15.* Lu, T., Cao, Q., Pang, X. H., Xia, Y. Z., Xun, L. Y. & Liu, H. W. Sulfane sulfur-activated actinorhodin production and sporulation is maintained by a natural gene circuit inStreptomyces coelicolor. *Microbial Biotechnology* 13, 1917-1932, doi:10.1111/1751-7915.13637 (2020). | *3* | |
| *16.* Xiong, T. Q., Wei, Q. S., Zhai, W. D., Li, C. L., Wang, S. Y., Zhang, Y. X., Liu, S. J. & Yu, S. Q. Comparing Subsurface Seasonal Deoxygenation and Acidification in the Yellow Sea and Northern East China Sea Along the North-to-South Latitude Gradient. *Frontiers in Marine Science* 7, doi:10.3389/fmars.2020.00686 (2020). | *3* | |
| *17.* Zheng, L.-W., Zhai, W.-D., Wang, L.-F., et al. Improving the understanding of central Bohai Sea eutrophication based on wintertime dissolved inorganic nutrient budgets: Roles of North Yellow Sea water intrusion and atmospheric nitrogen deposition. Environmental Pollution, 2020, 267, 115626. doi: 10.1016/j.envpol.2020.115626 | *3* | |
| *18.* Zhang, W.-Z., Chai, F., Xue, H. & Oey, L.-Y. Remote sensing linear trends of the Gulf Stream from 1993 to 2016. Ocean Dynamics, | *3* | |

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|---|---|---|
| 1-12 (2020). doi: 10.1007/s10236-020-01356-6 | | |
| *19.* Dong, L., Zhang, X., Jia, G., Du, Y., Li, L., & Li, Q., 2020. $CO_2$-induced decoupling of tropical surface and thermocline water temperature at the onset of interglacials. Geophysical Research Letters, 47, doi: 10.1029/2020GL088805. | *3* | |
| *20.* Zhang, J., Yu, Z., Jia, G., 2020. Cyclisation degree of tetramethylated brGDGTs in marine environments and its implication for source identification. Global and Planetary Change, 184, 103043, doi.org/10.1016/j.gloplacha.2019.103043. | *3* | |
| *21.* Yang, Y., Ruan, X. Y., Gao, C., Lu, X. X., Yang, H., Li, X. J., Yao, Y. J., Pearson, A. & Xie, S. C. Assessing the applicability of the long-chain diol (LDI) temperature proxy in the high-temperature South China Sea. *Organic Geochemistry* 144, doi:10.1016/j.orggeochem.2020.104017 (2020). | *3* | |
| *22.* Zhu, X. W., Jia, G. D., Mao, S. Y., Sun, Y. G., Wu, N. Y., Tian, Y. H., Xu, W. H. & Yan, W. Long chain 1,14-diols as potential indicators for upper water stratification in the open South China Sea. *Ecological Indicators* 110, doi:10.1016/j.ecolind.2019.105900 (2020). | *3* | |
| *23.* Wei, B. B., Jia, G. D., Hefter, J., Kang, M. Y., Park, E., Wang, S. Z. & Mollenhauer, G. Comparison of the U-37(K'), LDI, TEX86H, and RI-OH temperature proxies in sediments from the northern shelf of the South China Sea. *Biogeosciences* 17, 4489-4508, doi:10.5194/bg-17-4489-2020 (2020). | *3* | |

**If appropriate, please list the IMBeR activity through / by / from / during which the publication arose*

*******Notes on publications*******

Publications are logged in the IMBeR Zotero library which is publicly accessible online - https://www.zotero.org/groups/2448334/imber_library_2/library

[Due to space limitations, publications from 1999-2017 are in a separate Zotero library - https://www.zotero.org/groups/38770/imber_library_1/library]

Publications are categorised by “Class” and linked to “Activities”:

***Class 1 publications*** are specifically generated through/by/from/during ***IMBeR activities*** - for example, arising from IMBIZOs and IMBeR conferences such as the IMBeR open science meeting and the IMBeR CJK symposia and from the activities of the working groups, regional programmes and the SPIS scoping teams.

***Class 2 publications*** are on topics relevant to the IMBeR Science Plan that benefitted from some interaction with IMBeR or ***IMBeR activities***, for example by IMBeR symposium attendees, past and present SSC members, working group, regional programme and endorsed project members, or national contacts.

***Class 3 publications*** are on topics relevant to the IMBeR Science Plan but for which there is no direct link to or benefit from an IMBeR activity. These might include publications by SSC members, working group, regional programme or endorsed project members or members of the IMBeR international community that were written as part of the normal scientific activity of the authors and would have occurred irrespective of IMBeR's existence. You can report Class 3 publications, but they will no longer be logged in the IMBeR database.

[See https://drive.google.com/open?id=1OQWn41KJvQ-LyWJlkiYnc5qZ2IuNQOrg or https://pan.ecnu.edu.cn/p/DTrpUb4QiFAYoQ4 for further information on "What is an IMBeR publication?".]

***Why list 'Class' and 'Activity'?*** This helps us to declare authentically which publications IMBeR has helped to generate, and it makes it easier for us to demonstrate the value of the Regional Programmes, the Working Groups, the Endorsed Projects, and IMBeR in general, and it helps us to justify support for IMBeR activities when we can list tangible outputs.

### 1.c. Events, Meetings, and Workshops

*List all international and national events, meetings and workshops. Describe the level of participation: e.g. chairing session/workshop, organising meeting. Include Endorsed Project meetings and workshops.*

*Format: Title of event. Date. Location. Description of participation. Any other pertinent details.*

Annual academic meetings for the project (online), Jan 18, 2021, China.

All members of the project attended the meeting and discussed quantitative results of MCP model in the South China Sea and the global assessment of organic carbon in marine sediments

## 2. International collaboration and links

Since the world-wide pandemic of COVID-19 in 2020, international collaboration was severely limited. Some international voyages and international conferences had to be cancelled or delayed. Though, international communications were moved online through online meetings or invited online presentations.

## 3. Input to management, policy and governance

*Add anything that in line with the IMBeR Grand Challenge III: Improving and achieving sustainable ocean governance*

### 3.a. Input to management and policy over the last year

*Add anything that in line with the IMBeR Grand Challenge III: Improving and achieving sustainable ocean governance*

*The management and policy were generally consistent during the past five years as summarized below.*

### 3.b. Input to management and policy – Highlights from past 5 years

- ✓ Good internal management mechanism, involving the sharing and marking of achievements, irregular academic meetings, research progress briefing, key scientific issues of the project, academic ethics, fund management, conclusion, data management were formulated at the beginning of the project.

- ✓ Members in this project discuss the progress and cooperation of the project online from time to time. Meanwhile, the project members carry out some small-scale academic discussions via the domestic and international academic exchange activities.

- ✓ Members organized some joint voyages to collect and analyse the samples in the South China Sea, Bohai Sea and East China Sea.
- ✓ The first group and the second group cooperate to solve the first key scientific problem of marine carbon storage mechanism, to answer the interaction process of BP and MCP in the ocean water column and the amount of carbon stored in it. Meanwhile, a physical-ecological coupling model suitable for the northern South China Sea was established to simulate the interaction process of BP and MCP in the northern South China Sea.

## 4. Education and outreach

In 2020, eighteen students got the Master degree and ten students got Doctoral degree.

## 5. Planned activities for next year

Our project will be completed on June, 2021. An online meeting is planned in May 2021 for presenting the outcomes during the execution of the project.