

**RESEARCH GRANTS COUNCIL
THEME-BASED RESEARCH SCHEME (TRS)**

Completion Report on Funded Project

Project start date: 1st Jan., 2017
Project completion date: 31st Dec., 2022

1. Project Title: Diagnosis and prognosis of intensifying eutrophication, hypoxia and the ecosystem consequences around Hong Kong waters: coupled physical-biogeochemical-pollution studies

2. Names and Academic Affiliations of Project Team Members[#]

Project team member	Name / Post	Unit / Department / Institution	Average number of hours per week spent on this project in the current reporting period
Project Coordinator (PC)	Prof. Jianping Gan/ Chair Professor	Department of Ocean Science & Department of Mathematics, The Hong Kong University of Science and Technology (HKUST)	24
Co-Principal Investigator(s)	Prof. Paul Kwan Sing Lam/ President & Chair Professor	Hong Kong Metropolitan University (formerly The Open University of Hong Kong)	14
	Prof. Minhan Dai/ Academician of Chinese Academy of	State Key Laboratory of Marine Environmental Science, Xiamen University	14

	Science, Director and Chair Professor	(XMU)	
	Prof. Hongbin Liu/ Chair Professor	Department of Ocean Science & Division of Life Science, The Hong Kong University of Science and Technology (HKUST)	14
Co-Investigator(s)	Prof. David Michael Baker/ Associate Professor	The Swire Institute of Marine Science, School of Biological Sciences, The University of Hong Kong (HKU)	12
	Prof. Leo Lai Chan/ Associate Director	State Key Laboratory of Marine Pollution, City University of Hong Kong (CityU)	12
	Prof. Ji Chen/ Professor	Department of Civil Engineering, The University of Hong Kong (HKU)	12
	Prof. Jiang Zhu/ Professor	Institute of Atmospheric Physics, Chinese Academy of Sciences (CAS)	12
	Prof. Stanley C K Lau/ Associate Professor	Department of Ocean Science, Division of Environment & Sustainability & Division of Life Science, The Hong Kong University of Science and Technology (HKUST)	12
	Prof. Shih-Nan Chen/ Professor	Institute of Oceanography, National Taiwan University	12
	Prof. Jiying Li/ Assistant Professor	Department of Ocean Science, The Hong Kong University of Science and Technology (HKUST)	12
Collaborators	Prof. James C. McWilliams/ Louis B. Slichter Professor	Department of Atmospheric and Oceanic Science, University of California, Los Angeles (UCLA)	N.A.

	Prof. Donald Anderson/ Senior Scientist	Coastal Ocean Institute & Biology Department, Woods Hole Oceanographic Institution (WHOI)	N.A.
	Prof. Wei Jun Cai/ Mary A.S. Lighthipe Chair Professor	School of Marine Science and Policy, College of Earth, Ocean, & Environment, University of Delaware	N.A.

Please highlight the approved changes in the project team composition and quote the date when the RGC granted approval of such changes. For changes in the project team composition, please submit a separate request, together with the justification and the curriculum vitae of the new member(s), to the RGC three months prior to the intended effective date of the change.

- Prof. Wei Jun Cai (Chair Professor from Mary A. S. Lighthipe) replaced Prof. Paul Harrison as collaborator with approval obtained from the RGC on 27 September 2018.
- Co-Investigator Prof. Ang Put Jr. (Associate Professor from CUHK) left the project (due to his retirement) with approval obtained from the RGC on 4 January 2019.
- Prof. Onyx Wing Hong Wai retired from PolyU in mid-September 2020. A new faculty member Prof. Jiying Li, whose expertise lies in sediment biogeochemistry which fits the needs of the project, has joined the team as a new Co-I to replace Prof. Wai. Approval was received from the RGC on 20 October 2020 for the personnel change and the corresponding change in budget.
- Prof. Paul Kwan Sing Lam changed his affiliation from CityU to Hong Kong Metropolitan University (formerly the Open University of Hong Kong) on 1 April 2021.
- Prof. Ji Chen was promoted to Professor of The University of Hong Kong with effect from 1 May 2020.
- Prof. Shih-Nan Chen was promoted to Professor of National Taiwan University in 2020.
- Prof Hongbin Liu was promoted to Chair Professor of HKUST on 1 July 2021.

3. Project Objectives

Summary of objectives addressed/achieved:

Objectives*	Percentage achieved	Remarks**
1. Sources and sinks of nutrients and their biogeochemical controls	100%	
2. Ecosystem dynamics and biological controls	100%	
3. Pollutant and ecosystem impacts	100%	
4. Physical controls, synthesis, and future trends in the RES	100%	

Objectives*	Percentage achieved	Remarks**
waters		

* Please highlight the approved changes in objectives and quote the date when the RGC granted approval of such changes.

** Please provide reasons for significantly slower rate of progress than originally planned.

6. Research Highlights and Outputs

6.1 What are the most exciting research accomplishments of the project?

(Please list five or more of the team's best research accomplishments, such as journal and conference papers, software codes, research infrastructure, etc. For each item, please clearly justify how it has achieved international excellence (e.g. best paper award, invited presentation, citations, product licensed to industry, etc.))

1. We conducted unprecedented interdisciplinary field measurements. Based on these measurements and an innovative numerical modeling method, we developed a coupled physics-biogeochemistry model that can be used to diagnose and prognose the hydrodynamics, ecosystem and eutrophication, and hypoxia. For the first time, this TRS project holistically provides scientific evidence to explain when, where, and how eutrophication and hypoxia occur in the waters off Hong Kong and the Greater Bay Area (GBA).

2. We found that eutrophication-derived organic matter (OM) accounted for ~65% of total oxygen consumption in the bottom hypoxic waters, while terrestrial OM directly contributed ~30% and indirectly promoted hypoxia development by releasing nutrients. The bottom hypoxia reduced the acid-base buffering capacity of seawater and seriously aggravated coastal acidification.

3. We proposed oyster farming as a promising approach to mitigate eutrophication and hypoxia under the inevitable stressor of fertilizer discharge. We found that an oyster farming area of 10 to 200 km² can yield a 6% to 67% reduction in hypoxic volume, equivalent to the impact of reducing the river nutrient load by 10% to 60%.

4. We discovered a new formation mechanism for hypoxia in the GBA which was never reported and provided new insight into the coastal hypoxia formation. We found that under the control of prevailing wind-driven current, the shoreward upslope transport of OM from the subsurface chlorophyll maximum offshore played a critical role in triggering hypoxia when river discharge was low, which otherwise would not occur.

5. For the first time, we discovered that P-limitation can reverse its impact from reducing to expanding coastal hypoxia via the interacting limitation-induced changes in surface production and bottom oxygen influx. This provides a new understanding of P-limitation for ecosystem dynamics in plume-affected coastal waters both in the GBA ocean and global coastal waters.

6. The project has launched the first Online Marine Environmental Visualization Platform in the region (WavyOcean, <https://ocean.ust.hk:8443/SiteMapApi/new/index.jsp>), which offers a “one-stop shop” for sharing scientific knowledge and data. WavyOcean can help policymakers strike a balance between marine conservation and social development (e.g. the Lantau Tomorrow Vision project) and provides a useful view of the time-dependent, three-dimensional hydrodynamics ecosystem and pollutants in the GBA ocean as well as in the entire China Seas. WavyOcean records about 100 visits and data downloads a day, and the mobile app has been downloaded over 3,000 times. Both this project and the WavyOcean platform have attracted great attention from mainstream media and the broader community.

These are evidenced by papers such as:

Li, D. and J. Gan, Z. Lu, W. Cheng, H. Kung and J. Li, 2023. Hypoxia formation triggered by the organic matter from subsurface chlorophyll maximum in a large estuary-shelf system *Water Research*. WR120063.

Dai, M., Y. Zhao, F. Chai, M. Chen, N. Chen, Y. Chen, D. Cheng and J. Gan et al., 2023. Persistent eutrophication and hypoxia in the coastal ocean, *Cambridge Prisms: Coastal Futures*, CFT-22-0058.R1.

Lai, W. and J. Gan, 2022. Impacts of high-resolution atmospheric forcing and air-sea coupling on coastal ocean circulation off the Pearl River Estuary. *Estuarine, Coastal and Shelf Science*, YECSS-D-22-00113.

Yu, L. and J. Gan, 2022. Reversing impact of phytoplankton phosphorus limitation on coastal hypoxia due to interacting changes in surface production and shoreward bottom oxygen influx. *Water Research*, doi: <https://doi.org/10.1016/j.watres.2022.118094>

Lu, Z., L. Yu and J. Gan, 2022. External and internal forcings for hypoxia formation in an urban harbour in Hong Kong. *Front. Mar. Sci.* 9:858715. doi: 10.3389/fmars.2022.858715.

Yu, L. and J. Gan, 2021. Mitigation of eutrophication and hypoxia through oyster aquaculture: an ecosystem model evaluation off the Pearl River Estuary. *Environ. Sci. Technol.*, <https://doi.org/10.1021/acs.est.0c06616>.

Li, D., J. Gan, C. Hui, L. Yu, Z. Liu, Z. Lu, S. Kao and M. Dai, 2020. Spatiotemporal development and dissipation of hypoxia induced by wind-driven shelf circulation off the Pearl River Estuary: observational and modeling studies. *J. Geophys. Res. (Oceans)*, 126, e2020JC016700.

Li, D., J. Gan, Rex Hui, Z. Liu, L. Yu, Z. Lu, M. Dai, 2020. Vortex and biogeochemical dynamics for hypoxia formation in the coastal transition zone off the Pearl River Estuary. *J. Geophys. Res. (Oceans)* 125, e2020JC016178.

Lu, Z., J. Gan, M. Dai, H. Liu and X. Zhao, 2018. Joint effects of extrinsic biophysical fluxes and intrinsic hydrodynamics on the formation of hypoxia west off the Pearl River Estuary. *J. Geophys. Res. (Oceans)*, doi: 10.1029/2018JC014199.

Yu, L., J. Gan, M. Dai, R. Hui, Z. Lu and D. Li, 2020. Modeling the role of riverine organic matter in hypoxia formation within the coastal transition zone off the Pearl River Estuary. *Limnology and Oceanography*, doi: 10.1002/lno.11616. <https://aslopubs.onlinelibrary.wiley.com/doi/10.1002/lno.11616>

Zhao, Y. Y., J. Liu, K. Uthaipan, X. Song, Y. Xu, B. Y. He, H. B. Liu, J. Gan, and M. H. Dai, 2020. Dynamics of inorganic carbon and pH in a large subtropical continental shelf system: Interaction between eutrophication, hypoxia and ocean acidification. *Limnology and Oceanography*, LO-19-0165.

Liu, Z. and J. Gan, 2020. A modeling study of estuarine-shelf circulation using a composite tidal and subtidal open boundary condition. *Ocean Modelling*, 147 (2020) 101563. <https://www.sciencedirect.com/science/article/pii/S1463500319300174>

Lu, Z., J. Gan, M. Dai, H. Liu and X. Zhao, 2018. Joint effects of extrinsic biophysical fluxes and intrinsic hydrodynamics on the formation of hypoxia west off the Pearl River Estuary. *J. Geophys. Res. (Oceans)*, doi: 10.1029/2018JC014199.

- 6.2 What was the added value of the TRS funding, rather than standard project grant funding?
(For example, could this work have been achieved with other funding scheme, such as the General Research Fund or Collaborative Research Fund? If not, why?)

The results of this project could not have been achieved with GRF or CRF funding. The TRS funding has enabled us to increase our impact across many levels of society from government

to the public. Through the project, we have built relationships with stakeholders, including policymakers in government agencies, the general public, and industry professionals.

6.3 If the project has not met its original objectives, why?

N.A.

6.4 (a) Please provide details of each peer-reviewed journal publication arising directly from this project by completing the table at **Annex** (*one for each publication*).

A total of 83 journal papers have been published. Please refer to the annex for details.

(b) Please provide details of recognised international conference(s) in which paper(s) related to this project was/were delivered by completing the following table:
(*Please attach a copy of each conference abstract*)

See Appendix I.

(c) RGC funding should have been acknowledged in all publication(s)/conference papers listed in (a) and (b) above. If no acknowledgement has been made in any of the publications/ papers, please indicate and provide explanations.

N.A.

6.5 To what extent this project has strengthened inter-institutional collaborations and other partnerships?

Based on the platform of this project, we have strengthened our research collaborations by integrating expertise, manpower, and facilities from different institutions to conduct large-scale and interdisciplinary studies on eutrophication and hypoxia in the waters off Hong Kong and the GBA.

As a result of these collaborations, we have established the Center for Ocean Research in Hong Kong and Macau (<https://core-hkmacau.hkust.edu.hk/>) to consolidate the ocean research strengths in different institutes. We have also developed a newly funded AoE project (see section 9.2).

6.6 Research students trained (registration/awards):

This TRS project has provided training to a total of **26 PhD** and **10 MPhil** students. In addition to research students, we have also involved 1 Bachelor student and 11 Master students in this project.

Name	Degree registered for	Date of registration	Date of thesis submission/ graduation
Walter DELLISANTI	PhD in Biomedical Science	2017	2020
Xin LI	PhD in Environmental Science	2016	2019
Yu Hin LEUNG	MPhil in Biology	2013	2017
Feng XIAO	PhD in Civil Engineering	2016	2020

Yao TANG	MPhil in Environmental Science, Policy and Management	2017	2019
Chenmin YU	MPhil in Environmental Science, Policy and Management	2015	2017
Serena Man-Yon MCDONNELL	MPhil in Mathematics	2015	2017
Ying KE	MPhil in in Life Science	2015	2018
Zhiyuan SHI	MPhil in Marine Environmental Science	2016	2018
Dou LI	PhD in Marine Environmental Science	2017	2021
Wai Pang Aaron TSANG	MPhil in Mathematics	2017	2019
Fangzhou CHEN	PhD Environmental Science Policy and Management	2016	2020
Xiu Pei KOH	PhD Environmental Science Policy and Management	2016	2020
Yanhong LU	PhD in Marine Environmental Science	2016	2020
Zhimeng XU	PhD in Marine Environmental Science	2017	2021
Lok Yi TANG	PhD in Marine Environmental Science	2017	2021
Jinsen ZENG	Bachelor in Environmental Engineering	2014	2018
Jianming XIE	Master in Biology	2016	2019
Song Xue	Master in Marine Chemistry	2016	2019
Shilei JIN	Master in Marine Chemistry	2016	2019
Zhongwei YUAN	Master in Marine Chemistry	2017	2020
Shengyao SUN	Master in Marine Geology	2014	2017
Jianzhong SU	PhD in Marine Chemistry	2014	2019
Khanittha UTHAIPAN	PhD in Marine Chemistry	2016	2020
Feifei MENG	PhD in Marine Chemistry	2014	2018
Yangyang ZHAO	PhD in Marine Chemistry	2016	2020
Jing LIU	PhD in Marine Chemistry	2017	2021
Weizhen JIANG	PhD in Marine Chemistry	2019	2023
Zixiang YANG	Master in Marine Chemistry	2017	2020
Chi Wing HUI	PhD in Environmental Science Policy and Management	2019	2026
Yingdong LI	PhD in Marine Environmental Science	2016	2019
Huo XU	PhD in Marine Environmental Science	2018	2021
Xiaodong ZHANG	PhD in Marine Environmental Science	2018	2021
Sze Ki LEUNG	PhD in Marine Environmental Science	2017	2020
Qi WANG	PhD in Environmental Science	2019	2022
Junlu LI	PhD in Marine Environment Science	2015	2019
Tsz Kwan WONG	MPhil in Marine Environment Science	2018	2020

Yan Yin Jenny CHEUNG	MPhil in Marine Environmental Science	2019	2021
Jing SUN	PhD in Marine Environmental Science	2020	2024
Lei ZHOU	MPhil in Marine Environmental Science	2020	2021
Yanmin WANG	PhD in Marine Chemistry	2020	2024
Yaohua LUO	PhD in Marine Chemistry	2020	2025
Ying GAO	Master in Marine Chemistry	2018	2021
Guiyuan DAI	Master in Marine Chemistry	2018	2021
Yi YANG	Master in Marine Chemistry	2019	2022
Wenjing LV	Master in Marine Chemistry	2019	2022
Fei ZHANG	Master in Marine Chemistry	2020	2023
Ying ZHANG	PhD in Marine Environment Science	2021	2024

6.7 Specific products (e.g. software or netware, instruments or equipment developed):

We have developed an ocean visualization platform, WavyOcean (<https://ocean.ust.hk:8443/SiteMapApi/new/index.jsp>), for Hong Kong and GBA waters (Fig. 1). WavyOcean has already attracted substantial regional and global attention. The mobile app version of the platform has received over 3,000 downloads and the data has been downloaded or viewed more than 23,000 times worldwide since its launch in January 2022 (see Fig. 3 below). The data includes time-dependent, three-dimensional physical and biogeochemical parameters and pollutant fluxes for building regional environmental benchmarks, understanding the status, and aiding development, such as the grand reclamation project proposed by the Hong Kong government. The outcomes have drawn attention both locally and globally (see Fig. 4 below).

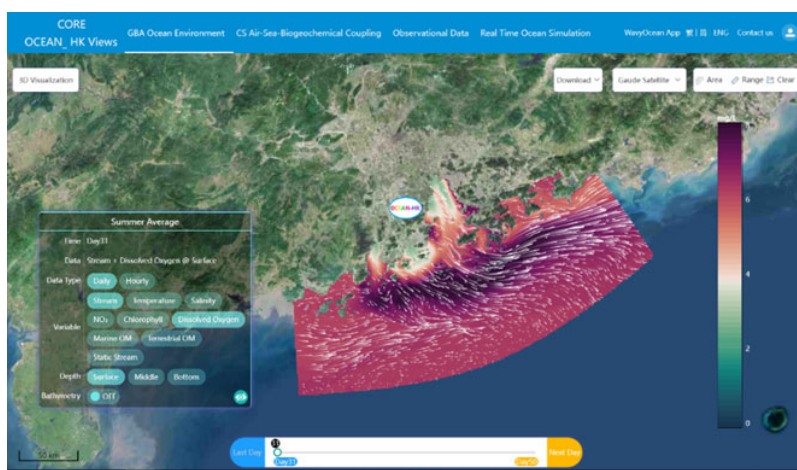


Fig. 1 Example of 2D representation of ocean hypoxia in the GBA from the WavyOcean interactive platform created in the TRS project.

6.8 Other education activities and/or training programmes developed:

N.A.

6.9 Please highlight any deliverables indicated in the project implementation timetable endorsed by the RGC which have not been covered or achieved as per sections 6.1 to 6.8 above, and

explain/ elaborate.

N.A.

Project Management

6.10 Please elaborate how the PC has played his/her role in coordinating and managing the project.

The PC led the Project Steering Committee (PSC). Assisted by the International Advisory Committee (IAC), he oversaw project implementation, monitored the research quality, and liaised with stakeholders. Together they provided governance and guidance for the four tasks led by the four respective PIs (Fig. 2). The PC formed and led the project office (PO) which consisted of a manager, an administrative assistant, a Field-work Management Subcommittee, and a Data Management Subcommittee to coordinate and implement the project. The PC coordinated the daily operation of the project through the PO. Given the large-scale and multidisciplinary nature of the project, the PC also created different disciplinary and interdisciplinary working groups with members from different tasks to serve the needs of the project. The PC presided over regular workshops at both the project and task levels as well as an annual project symposium.

Administrative structure

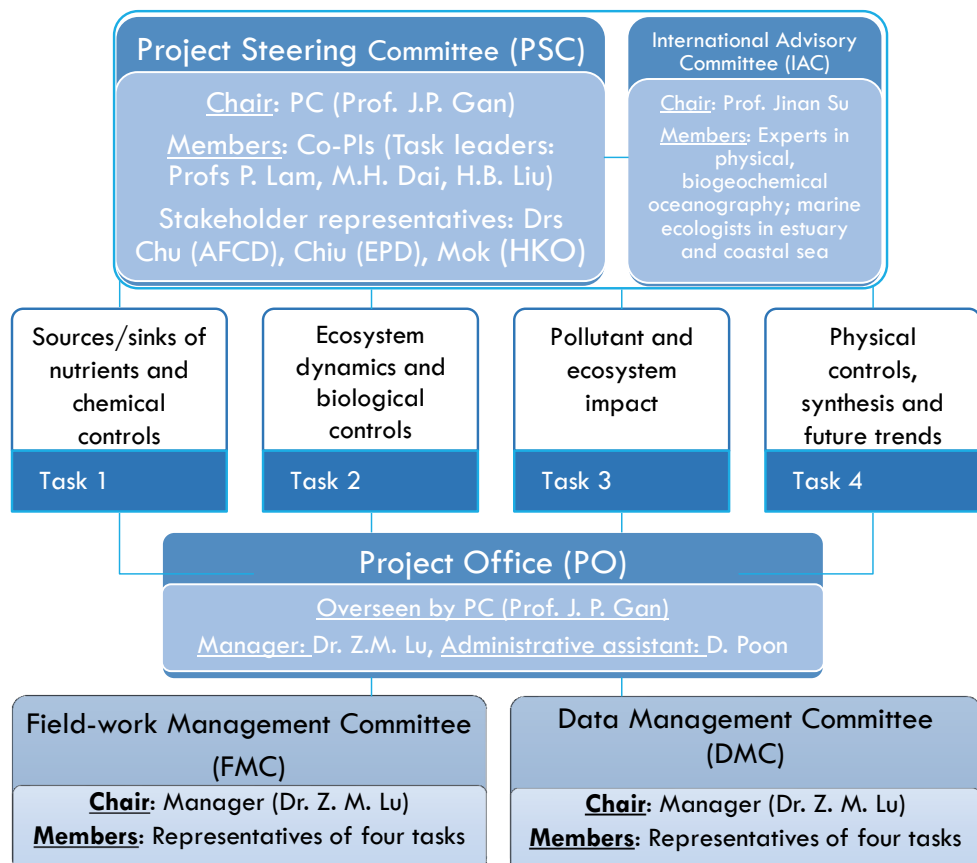


Fig. 2. Structure of governance under the PC.

7. Awards and Recognition

7.1 Have any research grants been awarded that are directly attributable to the results obtained from this project?

1. This TRS is an integral part of COASTAL-SOS, which is a project endorsed by the United Nations Decade of Ocean Science for Sustainable Development (2021- 2030).
2. An AoE project titled “Study of the regional earth system for sustainable development under climate change in the Greater Bay Area” (total approved budget is HKD 87.147 million) (<https://earthhk.hkust.edu.hk/>).

7.2 Have any project team members participated as invited speakers in or organisers of international conferences as a result of this project?

Prof. Jianping Gan gave an invited keynote presentation entitled “Coupled Physical-Biogeochemical Study of Eutrophication/Hypoxia in the Pearl River Estuary off Hong Kong” at the International Ocean Deoxygenation Conference held in Kiel, Germany, Sept 02-07, 2018.

Prof. Jianping Gan delivered a talk titled "Diagnosis and prognosis of intensifying eutrophication, hypoxia and ecosystem consequences around Hong Kong waters: coupled physical-biogeochemical-pollution studies" at the International Workshop on Ocean Sustainability in the Greater Bay Area of the Pearl River Delta co-sponsored by the China Council for International Cooperation on Environment and Development (CCICED) Special Policy Study on Ocean Governance, this TRS project, and State Key Laboratory of Marine Environmental Science (Xiamen University), Jan 28-29, 2019, Hong Kong.

Prof. Jianping Gan delivered a talk titled "Coupled physics-biogeochemistry modeling study in multi-scale China Sea system" at the 4th Global Ocean Acidification observing Network (GOA-ON) International Workshop, Apr 14-17, 2019, Hangzhou, China.

Prof. Jianping Gan delivered a talk at "Blue Economy in the GBA: Environment Prospective", Special Project Team for Greater Bay Area (GBA) Assignment, Policy Innovation and Coordination Office (PICO), July 3, 2019, Hong Kong.

Prof. Jianping Gan gave an invited presentation entitled “Monitoring, understanding and predicting eutrophication and hypoxia in off Pearl River Estuary” at the International Ocean Science Biennial Conference 2019, Oct 2019, Sanya City, China.

Prof. Jianping Gan gave an invited presentation entitled “On Ocean Circulation, Ecosystem and Hypoxia along the coastal transition zone off Hong Kong (OCEAN_HK)” at the International symposium on coastal ecosystem change in Asia, Nov 2019, Matsuyama, Japan.

Prof. Minhan Dai attended the 11th International Symposium on Geochemistry of the Earth’s Surface held in Guiyang, China during June 11-16, 2017 and gave an invited plenary presentation entitled “On the eutrophication, hypoxia and ocean acidification at the land-ocean interface”.

Prof. Minhan Dai gave a keynote presentation entitled “Perspectives Towards Ecosystem-Based Management of the Great Bay Area of the Pearl River Delta” at the International Symposium on Blue Economy and Marine Conservation held in Kunshan, China

on June 2, 2018.

Prof. Minhan Dai gave an invited presentation on “The environmental situation of the China Seas: An overview” at the International Symposium on Development of the Maritime Economy and Sustainability of Seas and Oceans: The cases of China and European Union, which was held in Hong Kong during June 7-8, 2018.

Prof. Minhan Dai attended the coastal session in the international conference on “Ocean deoxygenation: drivers and consequences, past, present, future”, Kiel, Germany on September 3-7, 2018 as a co-chair.

Prof. Minhan Dai attended the Fourth Global Ocean Acidification Observing Network (GOA-ON) International Workshop, April 14-17, 2019, Hangzhou, China as a co-chair. He also attended the Ocean Obs'19 conference program committee meeting, September 16-20, 2019, Hawaii, USA as a co-chair.

Prof. Minhan Dai attended the Ocean Sciences section of AGU Fall Meeting, December 9-13, 2019, San Francisco, USA as an Executive Committee Member.

Prof. Minhan Dai was invited to the First Workshop of the WESTPAC Ocean Oxygen Network (O2NE), November 20-22, 2019, Manila, the Philippines, in which he gave three talks: 1. Eutrophication, hypoxia, and ocean acidification in the coastal ocean, 2. Ocean Obs'19 & BIO-ARGO, and 3. Deoxygenation in the open ocean and coastal areas in WESTPAC.

Prof. Hongbin Liu was the organizer of a Croucher Foundation Summer Course on Global Change and Marine Ecosystems from 30 Jun – 6 July 2019. This five-day summer course aimed to provide students with a systematic and comprehensive overview of the impact of global climate change and the rapid increase in atmospheric CO₂ on ocean ecosystems, with a particular focus on the three major impacts of ocean warming, ocean acidification and hypoxia.

7.3 Have any project team members taken leadership positions in editorial boards, scientific and professional organisations?

Prof. Jianping Gan is 1) Associate Editor, Journal of Applied Oceanography 2008-; 2) Member of Editorial Board, Acta Oceanologica Sinica, 2012-; and 3) Special-issue Editor, Progress in Oceanography, 2019-.

Prof. Paul K.S. Lam is 1) Editor-in-chief, Journal of Aquatic Toxicology; 2) Associate Editor, Journal of Environmental Sciences; and 3) Member of the Editorial Advisory Board, Environmental Science and Technology during the TRS project.

Prof. Minhan Dai is or was 1) Chair, Chinese Society of Marine Chemistry, Jan 2000-; 2) Member of Carbon & Climate Section, North Pacific Marine Science Organization (PICES), 2009-2019; 3) Member, The academic committee on marine areas of the Chinese Academy of Sciences, July 2017-June 2022; 4) Member, Scientific Committee, the 52nd International Liege Colloquium, 2019-; 5) Member, High Level Panel for a Sustainable Ocean Economy (HLP) Expert Group, 2019-; and 6) Participant, RECCAP2 (REgional Carbon Cycle Assessment and Processes-2), 2019-2021. He is or was also 1) Member of Editorial Board, Biogeosciences, EGU, 2007-; 2) Associate Editor, Marine Chemistry, 2010-2018; 3) Section Editor, “Elemental Distribution” section, the third edition of the Encyclopedia of Ocean

Sciences, 2017-2018 ; 4) Editor, National Science Review, 2015-; 5) Editor, Journal of Oceanology and Limnology, 2019-; 6) Special-issue Editor, Progress in Oceanography, 2019-; and 7) Associate Editor, Global Biogeochemical Cycles, 2020-.

Prof. Hongbin Liu is 1) Member, Red Tide Expert Advisory Group (RTEAG), HKSAR; 2) Member, Dumping at Sea Appeal Board Panel, HKSAR. He is also 1) Editorial Board Member, Journal of Plankton Research, 2008-; 2) Editorial Board Member, Scientific Reports 2014-; 3) Editorial Board Member, PLoS One 2018-; 4) Associate Editor, Frontiers in Marine Science 2014-; 5) Associate Editor, Frontiers in Microbiology 2016-; 6) Associate Editor, Estuaries and Coasts 2019-; and 7) Special-issue Editor, Progress in Oceanography, 2019-.

Dr. Leo Lai Chan is 1) Expert Member of Policy Expert Advisory Committee of Shenzhen municipal government; 2) Scientific Diving Consultant for Marine Science Committee of the Hong Kong Underwater Association; 3) Expert Advisory Committee of China Coral Conservation Alliance; 4) Scientific Advisor for Coral Reef Branch of the Pacific Society of China; 5) Expert member for the 6th National Marine Technology Forecast Working group under Ministry of Science and Technology of China; and 6) Chairman, Hydro-Environment Engineering and Research – Hong Kong Chapter (IAHR-HK) during the TRS project.

Prof. Ji Chen is or was 1) President, HS (Hydrological Sciences) section of AOGS (Asia Oceania Geosciences Society), June 2018-June 2020; and 2) Associate editor of three SCI journals: Journal of Hydrology, Journal of Hydro-environment Research, and Stochastic Environmental Research and Risk Assessment during the TRS project.

Prof. Stanley C K Lau is the Associate Editor of Frontier Marine Science.

7.4 Any documentary proof of the application of technologies arising directly from this project?

We have been licensed with our WaveOcean app.



7.5 Other awards and recognitions as a result of this project (please specify):

Prof. Hongbin Liu was elected by The Association for the Sciences of Limnology and Oceanography (ASLO) as “ASLO Fellow” in 2019 with an award ceremony in February 2020 during Ocean Science Meeting in San Diego. ASLO Fellows are recognized as having achieved excellence in their contributions to ASLO and the aquatic sciences.

8. Impacts

8.1 What are the current and expected impacts of the project on the long-term development of Hong Kong (social or economic development, e.g. patent, technology transfer, collaboration with external organisations, etc.)?

We have been approached by several government agencies (e.g., the Environmental Protection Department (EPD), the Civil Engineering and Development Department (CEDD), the Electrical and Mechanical Services Department (EMSD), and Hong Kong Observatory of SAR) and nongovernmental organizations (e.g. WWF Hong Kong) for advice and suggestions on sustainable development in the GBA. Specifically, we provided extensive advice and consultation to the CEDD, EPD, and Policy Innovation and Coordination Office regarding the environmental assessment for the large reclamation project to the east of Lantau Island near the HK airport (also called the Lantau Tomorrow Project). The PC has been invited to meet different government agencies of HKSAR to provide advice and guidance on ensuring water quality in the ocean of Hong Kong and the GBA for the Lantau Tomorrow Project. Our work has also attracted greater public attention, given broader concerns about environmental sustainability locally and globally (Figs. 3 and 4).

Media coverage

WavyOcean



Fig. 4. Media (partial) coverage of WavyOcean.

In summary, we have achieved the following academic and social impact:

1. Our project has attracted attention on coastal ocean research tackling eutrophication and hypoxia regionally and globally.
2. Our research provides science-based knowledge for developing cost-effective strategies to ensure sustainable water quality in Hong Kong and the broader GBA.
3. Our advanced modeling system, observational data, and research results have benefited the research community, government agencies, stakeholders, and the general public.
4. The first Online Marine Environmental Visualization Platform offers a “one-stop shop” for sharing scientific knowledge and data that can help policymakers strike a balance between marine conservation and social development.
5. The scientific output from this project has been considered as a case study in a Special Policy Study on Global Ocean Governance and Ecological Civilization (2017–2019) sponsored by China Council for International Cooperation on Environment and Development.

8.2 Others (please specify):

N/A

9. Sustainability of the Project

9.1 Whether there are new ideas evolved directly from this project?

Built on this project, we developed a new research concepts of regional earth system on the

sustainable study and *digital-twin* GBA platform that combines field data, an earth system simulator, scientific and AI interpolation and extrapolation, and visualization to improve our capability to forecast and mitigate pressing environmental issues and hazards arising from rapid social and economic development and climate change in the GBA.

9.2 Whether there are new projects evolved directly from this project?

We have developed a new AoE research project titled “Study of the regional earth system for sustainable development under climate change in the Greater Bay Area” (<https://earthhk.hkust.edu.hk/>).

9.3 Whether there are new collaborations developed directly from this project?

We have developed a new AoE project and Center for Ocean Research in Hong Kong and Macau (CORE, <https://core-hkmacau.hkust.edu.hk/>) based on this TRS project.

9.4 Please give details on how much money and from which sources has been obtained/requested for the specific purpose of continuing the work started under this project.

Our new AoE project has been funded for a total of HKD 87.147 million. The project has several objectives:

(I) Investigate integrated terrestrial (river basin), oceanic, and atmospheric processes that govern the cross-sphere exchanges of material and energy in the RES.

(II) Diagnose the human activities and climate change and their interaction with the natural ecosystem of the GBA via a human-RES integrated assessment framework.

(III) Assess and quantify the key processes, environmental hazards, and their future trends and the underlying mechanisms across time and space in the GBA using the digital twin.

10. Statistics on Research Outputs

(Please ensure the statistics in this section are consistent with the information presented in other sections of this report.)

	Peer-reviewed journal publications	Conference papers	Scholarly, books, monographs and chapters	Patents awarded	Other research outputs (please specify)	
No. of outputs arising directly from this research project	83	87	0	1	Type	No.

11. Public Access of Completion Report

(PCs of projects funded in 2010/11 academic year or onwards are required to release the completion reports to the public through the RGC website. Completion reports containing information such as abstracts in non-technical terms, objectives, research output including the list of conference papers / publications / journals and research findings and contact information of PCs should be open to public access.)

Please specify the information, if any, that cannot be provided for public access and give the reasons.

Information that cannot be provided for public access	Reasons

12. The Layman's Summary

Eutrophication/hypoxia (oxygen concentration < 2 mg/L) in the bottom waters has been a hazard to the ecosystem and our living environment in Hong Kong and other coastal waters for decades. The oceanic waters in Hong Kong and the Greater Bay Area are affected by persistent and increasing eutrophication/hypoxia, which could offset the environmental improvements achieved through the costly Harbour Area Treatment Scheme over the last 10 years. This TRS project (<https://ocean.ust.hk/>), for the first time, holistically provides scientific evidence to explain when, where, and how this marine hazard occurs, predicts its long-term trend, and offers novel mitigation and management schemes.

Scientifically, this project achieved the following:

1. For the first time, seasonal eutrophication-driven bottom hypoxia covering a total area of more than 660-780 km² in coastal waters off Hong Kong was identified to be persistent along the coastal transition zone (CTZ) between the Pearl River Estuary and the adjacent continental shelf and attributed to joint biogeochemical and hydrodynamics conditions locally.
2. The eutrophication-derived organic matter (OM) accounted for ~65% of total oxygen consumption in the bottom hypoxic waters, while terrestrial OM directly contributed ~25% and indirectly promoted hypoxia development by releasing nutrients.
3. The bottom hypoxia reduced the acid-base buffering capacity of seawater and seriously aggravated coastal acidification.
4. The hypoxia in the CTZ exhibited remarkable spatiotemporal variability due to changes in the path of the nutrient-rich river plume, strength of mixing, and length of water residence time as a result of the variable coastal current. Hypoxia in Victoria Harbour was jointly determined by external influx and internal hydrodynamics and biogeochemical processes.

The project's impact includes:

1. It unveiled the formation mechanism of hypoxia, strengthened our oceanographic research capability, and provided much needed information to stakeholders and governments.
2. The project has launched the first Online Marine Environmental Visualization Platform in the region (WavyOcean, <https://ocean.ust.hk:8443/SiteMapApi/new/index.jsp>), which offers a “one-stop shop” for sharing scientific knowledge and data that can help policymakers strike a balance between marine conservation and social development (e.g. the Lantau Tomorrow Vision project). WavyOcean records about 100 visits and data downloads a day, and the mobile app has been downloaded over 3,000 times. Both this TRS project and WavyOcean have attracted great attention from mainstream media and the broader community.
3. The scientific output from this project has been considered as a case study in a Special Policy Study on Global Ocean Governance and Ecological Civilization (2017–2019) sponsored by China Council for International Cooperation on Environment and Development.
4. This project is an integral part of COASTAL-SOS, which is a project endorsed by the United Nations Decade of Ocean Science for Sustainable Development (2021-2030).