Progress Report on
South China Sea Fluvial Sediments and Environmental Changes (FluSed)

This report briefly introduces justification and objectives of the FluSed project, summarizes major activities and progress obtained in the last intersessional period (May 2021–April 2023), and plans the activities for the next intersessional period (May 2023–April 2025).

1. Introduction and justification

The South China Sea offers an excellent natural laboratory for studying source-to-sink transport process of fluvial sediments among the global marginal seas. Numerous rivers, including the world's large rivers (e.g., the Pearl River, the Red River, and the Mekong River) as well as small mountainous rivers (e.g., rivers in Taiwan), supply as much as 700 Mt/yr of observed suspended sediments to the South China Sea. Upon entering the sea, the fluvial sediments are further transported by various coastal, surface, and deep/bottom oceanic currents, which are related to the East Asian monsoon winds, intrusion of the subsurface Kuroshio Current, and deep water from the western Pacific through the Luzon Strait. The sediments have recorded detailed climatic and environmental changes occurring in land source regions both naturally and anthropogenically. Fluvial sediments in adjacent waters of the South China Sea (e.g., other marginal seas of the western Pacific and marginal seas of the northern Indian Ocean) have undergone similar source-to-sink processes, which together with the South China Sea sediments present broader regional and global environmental and climatic changes.

To understand the fluvial sediment supply to the South China Sea, the UNESCO Intergovernmental Oceanographic Commission's Sub-Commission for the Western Pacific (WESTPAC) initiated the project on South China Sea Fluvial Sediments and Environmental Changes (FluSed) at its Seventh Session in May 2008, and then decided to continue the project at its following Eighth Session in May 2010 until Thirteenth Session in April 2021. Over the last 15 years, the project has provided an excellent regional platform for scientists interested to advance their scientific knowledge and to stimulate new ideas on the South China Sea sediments and related climate changes.

2. Timeframe and objectives

Initiated in 2008, the project has made significant progress and is scheduled to run until 2027.

Scientific objectives of the project include:
(1) to investigate fluvial sediment source-to-sink process in the South China Sea;
(2) to reconstruct time-series variation of sediment transport and deposition in the past;
(3) to evaluate environmental change and human activity influences on fluvial sediments in the South China Sea.

3. Major activities, outputs & outcomes over the last intersessional period (May 2021–April 2023)

Although affected strongly by the Colid-19 pandemic during the intersessional period, the following activities were well organized, including two international workshops, two oceanic observation cruises, and severn sampling fieldtrips. Four young people participated in postdoc/PhD/master training programs, and six academic papers were published.

3.1. International workshops

Two international workshops (14th and 15th FluSed workshops) were organized in 2021 and 2022, respectively, on topics relevant to weathering and erosion in river drainage basins, sediment source-to-sink linkages, sea level changes in shelf and slope regions, deep-water sedimentation, and tectonic and magmatic evolution. A total of 83 participants from 13 countries joined the workshops.

“Fourteenth International Workshop on the Fluvial Sediment Supply to the South China Sea” (14th FluSed Workshop) was held virtually on 18 December 2021 through ZOOM meeting system (hosted by Prof. Zhifei Liu). Thirty-five participants from 11 countries joined the workshop, including Bangladesh (1), Cambodia (2), India (1), Indonesia (1), Malaysia (3), Philippines (2), Poland (1), Singapore (2), Thailand (3), Vietnam (3), and China (16). Total 15 oral presentations were given, followed by the plenary discussion for future collaboration.

“Fifteenth International Workshop on the Fluvial Sediment Supply to the South China Sea” (15th FluSed Workshop) was held virtually on 17 December 2022 through ZOOM meeting system (hosted by Prof. Zhifei Liu). Forty-eight participants from 12 countries joined the workshop, including Bangladesh (1), Cambodia (3), Canada (1), India (1), Indonesia (1), Malaysia (4), Myanmar (1), Philippines (10), Singapore (1), Thailand (2), Vietnam (7), and China (16). Total 19 oral presentations were given, followed by the plenary discussion for future collaboration.

3.2. Oceanic observation cruises

Two oceanic observation cruises were organized during May 2021 and August 2022 off the Mekong River in the southern South China Sea for maintaining (deploying and recovering) one observation mooring system equipping with moored sediment traps. Eight participants from Tongji University joined each of cruises. Suspended sediments collected by the sediment traps are used for terrigenous component analysis for tracking source-to-sink transport process from the Mekong River to the deep South China Sea.

3.3. Sampling fieldtrips

During the last intersessional period, seven sampling fieldtrips were organized along the Brahmaputra-Ganges river system in India and Bangladesh and the Mekong River system in Thailand, Laos, Cambodia, and Vietnam. These fieldtrips include: (1) the Ganges River (Bangladesh) during 10-15 January 2021, (2) the Brahmaputra River (India) during 18-28 February 2021, (3) the Mekong River (Cambodia) during 1-11 March 2021, (4) the Mekong River (Thailand and Laos) during 9-29 March 2021, (5) the Mekong Delta (Vietnam) during 9-13 April 2021, (6) the Tonle Sap Lake/the Mekong River (Cambodia) during 11-25 March 2022, and (7) the Brahmaputra River (India) during 5-18 October 2022. Totally about 210 sediment samples (mud and sand) were collected in these two world’s large river systems. These samples are being used in mineralogical and geochemical analyses to answer the source-to-sink transport processes and their associated chemical weathering and climate changes from the Tibetan Plateau to the Asian marginal seas (South China Sea and Bay of Bengal).

3.4. Postdoc/PhD/master training programs

During the last intersessional period, four young people participated in postdoc/PhD/master training programs in Tongji University. They are postdoc Pham Nhu Sang from Vietnam in 2019 and then continued to take the 2nd postdoc position in 2022, PhD student Fernandez A. Raymund from Philippines in 2017, PhD student Jirawat Deemuenwai from Thailand in 2020, and master student Sopheap Den from Cambodia in 2020. In addition, Dr. Suchana Taral from India was awarded as the Foreign Young Talents Program in 2021.

3.5. Publications

Six papers were published in international journals on collaborated topics of FluSed project.

[1] Yu, X., Liu, Z., Zeng, G., Cao, W., Meas, R., Hoang, V.L., Sang, P.N., 2022. Mantle plume-stagnant slab interaction controls the generation of a mixed mantle source for continental intraplate basalts. Lithos, 426–427: 106795.
[2] Sang, P.N., Liu, Z., Colin, C., 2022. Chemical weathering of the Mekong River basin with implication for East Asian monsoon evolution during late Quaternary: Marine sediment records in the southern South China Sea. Frontiers in Earth Science, 10: 885547.
[3] Jiwarungrueangkul, T., Liu, Z., Sompongchaiyakul, P., Jirapinyakul, A., Stattegger, K., 2022. Multi-proxy reconstructions of productivity on the continental slope off the Mekong

River in the southern South China Sea over the past 30,000 years. Palaeogeography, Palaeoclimatology, Palaeoecology, 597: 111005.
[4] Lin, B., Liu, Z., Eglinton, T.I., Blattmann, T.M., Kandasamy, S., Haghipour, N., Siringan, F.P., 2021. Organic matter compositions and loadings in river sediments from humid tropical volcanic Luzon island of the Philippines. Journal of Geophysical Research: Biogeosciences, 126: e2020JG006192.
[5] Jiwarungrueangkul, T., Liu, Z., 2021. East Asian monsoon and sea-level controls on clay mineral variations in the southern South China Sea since the Last Glacial Maximum. Quaternary International, 592: 1-11.
[6] Sang, P.N., Liu, Z., 2021. Terrigenous sediment variations in the western South China Sea and their implications to East Asian monsoon evolution during the last glacial-interglacial cycle. Quaternary International, 580: 1-10.

4. A summary of key achievements since its establishment

Over the last 15 years since the project has been established, significant achievements have been made in scientific research, cooperation and exchange, as well as young scientist training and capacity building. In particular, an excellent cooperation platform has been established among the project partner countries to provide with the frontier knowledge system on the South China Sea sediments and the impacts of natural climate change and human activities, as well as recommendations for adaptation and mitigation to extreme climate change. The following three key achievements have been obtained:

(1) Source-to-sink processes of fluvial sediments in the South China Sea and their controlling mechanism of climate change and oceanic current transport are revealed. Clay mineralogy and geochemistry of surface sediments from more than 150 major rivers and nearly 1500 sites on the seafloor of the South China Sea were investigated. The East Asian monsoon climate is determined as the main controlling factor for the formation of sediments surrounding the South China Sea, while the tectonic activities and lithologies play a secondary role. The fluvial sediments were transported mainly by oceanic current transport after being imported into the South China Sea, in which the differential settling and respective provenance also play important roles. The results reveal for the first time the mechanism of natural climate and oceanic current conditions in controlling sediment source-to-sink process the South China Sea.

(2) A high-level platform for regional cooperation and exchange on fluvial sediment and climate change in the South China Sea region has been well established. Annual international workshops (FluSed series, totally 15 workshops), dozens of bilateral academic visits of participating partners, and field sampling in rivers and offshore expeditions around and in the South China Sea have made the platform an important source of cutting-edge progress on source-to-sink process, attracting the attention of experts and young scientists in the South China Sea region and globally.

(3) Training of young talents and capacity building of partner institutions have been promoted. Tongji University has provided nearly 30 full scholarships to international students for master/PhD degree study. From laboratory analysis to publication, and to dissertation defense, the students can achieve the ability of independent research in the field of ocean science through systematic education and training. At the same time, the project has become one of the research objectives of partner institutions, which drive their laboratory and research capacity building, and provides important fundamental support for understanding of sediment transport and extreme climate change affected by natural and anthropogenic factors surrounding the South China Sea.

5. Self-assessment on implementation against objectives

Looking at three main scientific objectives of the project, we assess that the first two have been largely achieved over the past 15 years of implementation. The first two objectives are to study the sediment records (including surface sediments and sedimentary cores), to have obtained present-

day and past source-to-sink transport processes and their driving mechanism to climate change. However, it is actually difficult to distinguish between natural and human influences on source-to-sink processes using sediments that have been deposited. Thus, more research is needed to assess the impact of environmental change and human activities for the third objective. Therefore, over the past two years, this project has started to establish in-situ observation transects, e.g., from the Mekong River estuary to the deep southern South China Sea, and plans to continue the observation study in the next intersessional period, in order to obtain the daily, monthly, and seasonal scales of sediment transport processes and their natural climate change and human activity influences, respectively, so as to substantively achieve the third objective of the project.

6. Problems encountered and recommended actions

The last intersessional period (May 2021–April 2023) has been affected strongly by the Covid-19 pandemic, making international travel almost impossible. As a result, many activities were moved online, which reduced the efficiency of scientific discussion and communication. Our two international workshops (14th and 15th FluSed workshops) were organized through the ZOOM meeting system and reduced to a one-day meeting from previous two-day meeting. In addition, the planned observation in the Mekong River estuary using a River Bottom Node observation system was postponed due to the restriction on international travel, and it is now scheduled in summer of 2023. Planned bilateral scientific visits have also been cancelled for the same reason.

Fortunately, the Covid-19 pandemic has almost ended and all the partner countries of our FluSed project have been reopened since January 2023, with no restrictions on international travel. This brings excellent opportunities for the implementation of our project and in-person communication. Therefore, we plan to run this project until April 2027, to realize in-situ observations of sediment source-to-sink transport from estuaries to deep sea and the effects of climate change at two estuary-deep sea transects in the South China Sea.

7. Objectives to be achieved, if applicable, over the next intersessional period (May 2023–April 2025)

In the next intersessional period (May 2023–April 2025), the major objectives are: (1) to investigate fluvial sediment source-to-sink process by deploying in-situ observation systems from the estuaries to the deep basin of the South China Sea; two estuary-deep sea transects of the Mekong River to southwestern South China Sea and the Cagayan river to northeastern South China Sea will be observed to understand the transport dynamic process and response to extreme climate events (e.g., typhoon and extreme monsoon rainfall); (2) to obtain the sediment source-to-sink process of two world's river systems, the Lancang-Mekong river system and the Yarlung Zangbo-Brahmaputra-Ganges river system, both initiating in the Tibetan Plateau but ending at the South China Sea in Southeast Asia and the Bay of Bengal in South Asia, respectively. Both objectives will include the evaluation of natural environment change and/or human activity influences on sediment transport processes of the South China Sea and surrounding large river systems.

8. Planned activities for May 2023- April 2025

To achieve the above research objectives, the planned activities for the period of May 2023–April 2025 will include: (1) oceanic cruise investigations in the southwestern/northeastern South China Sea for deploying and recovering deep-sea mooring observation systems; (2) field observations at the Mekong River estuary and the Cagayan estuary by deploying and recovering the River Bottom Node observation system; (3) laboratory mineralogical and geochemical analysis on river sediment samples of the Lancang-Mekong and the Yarlung Zangbo-Brahmaputra-Ganges river systems collected in last two years; (4) organization of FluSed international workshops and of bilateral scientific visits and exchanges; (5) continuation of postdoc/PhD/master training programs hosted in Tongji University.

[provide, in tabular form, the action items that should be included in the work plan and budget]

Program					***Funding Required***		***Remark***
	Activities	***Objectives***	***Expected outputs/outcomes***	***Date and place***	***IOC***	***Other sources (i.e., from national or international)***	
South China Sea Fluvial Sediments (FluSed)	1. Oceanic observation cruise	Fluvial sediment source-to-sink transport mooring observation (sink)	Sediment transport and sinking mechanism in the deep sea	May 2023, South China Sea		US$100K (China)	
	2. Field/estuary observation	Fluvial discharge observation (source)	Sediment discharge and climate effect mechanism in the estuary	July 2023, Mekong delta (Vietnam)		US$60K (China)	
	3. Bilateral scientific visits	Science idea exchange and laboratory analysis	Publication and young scientist training	April 2023, Malaysia/China; June 2023, Thailand/China		US$10K (China)	
	4. 16th FluSed Workshop	Exchange of scientific results	Strengthening collaboration and discussion	November 2023, Shanghai (tentative)	US$10K	US$20K (China)	
	5. Oceanic observation cruise	Fluvial sediment source-to-sink transport mooring observation (sink)	Sediment transport and sinking mechanism in the deep sea	May 2024, South China Sea		US$100K (China)	
	6. Field/estuary observation	Fluvial discharge observation (source)	Sediment discharge and climate effect mechanism in the estuary	July 2024, Cagayan estuary (Philippines)		US$60K (China)	
	7. Bilateral scientific visits	Science idea exchange and laboratory analysis	Publication and young scientist training	April 2024, Cambodia/China; July 2024, Indonesia/China		US$10K (China)	
	8. 17th FluSed Workshop	Exchange of scientific results	Strengthening collaboration and discussion	November 2024, Singapore (tentative)	US$10K	US$20K (China)	
	TOTAL				US$20K	US$380K	